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SOVIET MARINE ICING DATA

by

W.P. Zakrzewski
and
E.P. Lozowski

ATMOSPHERIC ENVIRONMENT SERVICE

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Atmospheric Environment Service
4905 Dufferin Street
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Atmospheric Environment Service
Canadian Climate Centre
Marine Applications Unit
4905 Dufferin Street
Downsview, Ontario
M3H 5T4

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Prepared by

W.P. Zakrzewski
and
E.P. Lozowski

Division of Meteorology
University of Alberta
Edmonton, Alberta
T6G 2H4

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ABSTRACT

This report contains a comprehensive review of detailed field investigations of freezing spray carried out by the Soviets in the 1960's and 70's. More than one hundred Soviet reports (many previously not available in the West) were carefully reviewed to document the Soviet marine icing data collection programs, and to compile a data set of icing events suitable for model evaluation purposes. The authors had access to approximately 70% of the Soviet icing literature, including all of the most significant reports, and are confident that this review is an accurate representation of Soviet marine icing data collection programs up to about 1980 when there was a rather abrupt cessation of icing-related publications.

While it has been established that the Soviets collected more than 3500 ship icing reports, only a small fraction of these appear to have been analyzed and published. Even where reports were published, they were never complete and had to be pieced together by cross-referencing numerous documents. The authors were able to reconstruct about 100 documented icing cases with ice growth rate data for Soviet ships. A complete assessment of the quality of these data was beyond the scope of this report. However, it is expected to be considerably higher than the Stallabrass (1980) or Pease and Comiskey (1986) data sets because the icing data were measured by scientists as part of dedicated, well-funded field programs, where the above two data sets relied on voluntary information from vessels involved in commercial activities. In addition to compiling data on ice growth rates, the report contains a detailed review of (1) the splashing of Soviet ships with spray, (2) the climatology of Soviet marine icing, (3) ice loads due to icing, and (4) the density, porosity and adhesive strength of accreted ice.

RÉSUMÉ

Le présent rapport contient un examen exhaustif des études détaillées des embruns verglaçants menées sur les lieux par les Soviétiques dans les années 60 et 70. On a examiné plus de cent rapports soviétiques (dont beaucoup n'étaient jusqu'ici par disponibles dans l'Occident) pour étayer les programmes de collecte des données sur le givrage de la Marine soviétique et établir un ensemble de données sur les cas de givrage aux fins d'évaluation du modèle. Les auteurs avaient accès à environ 70 p. 100 des documents soviétiques sur le givrage, y compris tous les rapports les plus importants, et sont persuadés que le présent examen rend compte avec exactitude des programmes de collecte des données sur le givrage de la Marine soviétique jusqu'à 1980 environ, année où il y a eu une cessation assez abrupte des publications liées aux glaces.

On a établi que les Soviétiques ont recueilli plus de 3 500 rapports de navires sur les glaces, un faible pourcentage de ceux-ci ayant apparemment été analysé et publié. Même quand on avait publié des rapports, ils n'étaient jamais complets. Il fallait les réunir par des renvois à de nombreux documents. Grâce aux données du taux de croissance des glaces pour les navires soviétiques, les auteurs ont pu reconstituer une centaine de cas de givrage étayés. L'évaluation complète de la qualité de ces données dépassait le cadre du présent rapport. Toutefois, cette qualité devrait nettement dépasser celle des ensembles de données de Stallabrass (1980) ou de Pease et Comiskey (1986), car les données sur le givrage furent mesurées par des scientifiques en vertu de programmes spécialisés sur le terrain bien financés, programmes où les deux ensembles de données ci-dessus reposaient sur des renseignements communiqués bénévolement par des navires participant à des activités commerciales. Outre l'établissement de données sur les taux de croissance des glaces, le rapport renferme un examen détaillé de 1) le projection d'embruns sur les navires soviétiques, 2) la climatologie du givrage de la Marine soviétique; 3) les charges de glace attribuables au givrage et 4) la densité, la porosité et la force d'adhésion de la glace accumulée.

1. INTRODUCTION

There are no published data sets on ice growth rates on sea-going ships of sufficient credibility to permit the evaluation of detailed numerical models (Lozowski and Zakrzewski, 1987). However, two well-known data sets are available (Stallabrass, 1980; Pease and Comiskey, 1986).

Stallabrass (1980) gives 39 documented cases of ship icing for which the ice growth rate "on the ship" has been determined as well as the basic air-sea parameters (e.g., water and air temperature, relative wind speed, salinity of the water, etc.). This data set is based on the analysis of ship icing reports collected during the period 1970/71 - 1978/79 (exclusive of the season 1972/73). The given precision of the ice growth rates is very high (0.01 mm/h). While this work is an important first step in Canada, we feel that this data is not suitable for calibrating detailed three-dimensional ship icing models because of the method by which the data set was created.

First, the maximum ice thickness on various ship components (forward rails, forward stay, main deck, boat deck, house front, bulwarks) was visually estimated rather than accurately measured by the crew. Second, the average thickness of the ice deposit was determined as the arithmetical mean of the maximum ice thicknesses on the various ship components. This approach is not appropriate because the distribution of ice loads and the thickness of the ice deposits show great variability over the ship (Fig. 1.1). Detailed information on the ice load distribution over a fishing vessel may be found in Panov (1976) and Aksyutin (1979). For the same weather parameters the process of ice growth varies over the ship surface because of different values of the direct spray

Fig. 1.1. Icing on the Dutch chemical tanker "Anna Broere" which ran aground on the southern coast of the Baltic Sea during an icing storm (January 1, 1979).

fluxes impinging onto various parts of the ship. Moreover, many parts of the ship are not wetted at all, while others are exposed to spray under almost any weather conditions. The results of recent model studies of splashing a ship with collision-generated spray (Zakrzewski, 1986), lead one to conclude that the location of the target on the ship has a dramatic effect on the spray fluxes. Also, the heat fluxes from the various ship parts will be different, and the ice growth rates on the various ship parts will therefore be different too.

Third, the ice growth rates in the Stallabrass (1980) data set were calculated as the ratio of the above mentioned "mean value of the maximum thickness of the ice deposit on the ship" to the total duration of the icing event. The duration of the icing event was estimated based on the reported data. Such an approach is proper but only for determining the duration of the icing event for the entire ship, whereas the duration of icing on the various ship components is probably different. That is, when a ship experiences a storm, the wind speed and wave height are gradually rising, and the zone of spray coverage on the ship increases accordingly. When the storm is over, the wind speed and the waves diminish and consequently the extent of the zone affected by spray gradually decreases. Therefore, the duration of the spraying event varies over the ship. Taken altogether, we cannot recommend this data set for calibrating a detailed three-dimensional ship icing model.

The recently published data set of Pease and Comiskey (1986) presents 85 documented cases of ship icing in Alaskan waters for which the ice growth rates and basic air-sea parameters were determined based on ship icing reports. Although an effort has been made by Pease and Comiskey towards eliminating cases for which the ice growth rates on the

ships (estimated in a way similar to Stallabrass, 1980) were suspiciously too small or too large when compared with other growth rates experienced under similar weather conditions, we cannot recommend this data set for use either, for the following reasons. First, the values of ice thicknesses were once again estimated visually. Second, there is no information as to what parts of the ship the listed values of the ice growth rates refer to. However, the advantage of this data set is that Pease and Comiskey (1986) listed ship headings and pointed out cases in which the ship was operating in the open ocean.

These assessments of the available published data sets on ship icing lead one to the conclusion that to date there are no American or Canadian published data sets on ship icing of sufficient accuracy for model calibration. New field data of sufficient credibility are badly needed. Such data would need to be collected during several winter ship surveys, and the measurements should be conducted by research personnel trained for such work and using proper measuring systems. To obtain a sufficient number of well-documented cases of icing on ships, a comprehensive data collection program is required, and the data should be gathered on several ships over a few years. Because the cost of such a data collection program could be several hundred thousand dollars, it is unlikely that at present such a project could be launched either in Canada or in the United States.

Fortunately, two modest Canadian initiatives are already underway to help fill the gap in North American data sets on ship icing related parameters.

The first initiative is related to the data collection program launched at the University of Alberta with the cooperation of the

Memorial University of Newfoundland.

Based on our experience gained during this ship cruise in 1987, we plan a more comprehensive field experiment in winter 1987/88. In order to collect more field data on all the basic icing related parameters, we plan to put two of our staff on a Canadian ship operating in the cold Atlantic waters east of Canada in January/February 1988. The main objective of this survey is to obtain data on icing rates over the ship for various air-sea and ship motion parameters. These will be recorded by measuring equipment installed on the ship and operated by our personnel.

The second initiative is directly related to the present project. Because of Dr. Zakrzewski's involvement in research on the icing of ships and his careful collecting of the Soviet literature, we were aware of the possibility of obtaining high quality data on the icing of ships from published Soviet reports and journal papers. More than 100 Soviet papers (written exclusively in Russian*) were published in the 1960s and 1970s in the USSR. However, it seems that the Soviets suddenly and unexplainedly stopped publishing papers on ship icing in 1980-81. After a very careful search of all the information available, we are able to list only a few Soviet papers on marine icing published after 1980 (Kolosova and Panov, 1981; Voyevodin et al., 1981; Malakhov, 1982, Sharapov and Karpushin, 1983). However, these papers are really not of

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*Some reports have been translated into English by the USA Cold Regions Research and Engineering Laboratory and published in the form of Draft Translations.

the 'style' and 'scope' of the Soviet papers of the late 60s and 70s. We cannot give any explanation for this sudden break in the Soviet research that evidently resulted in discontinuing the publication of their reports on ship icing.

Our research proposal was aimed at looking through all available Soviet publications on icing and extracting from them relevant field data. In order to provide AES with organized data sets on icing-related parameters, we followed the schedule of research tasks given below (Lozowski and Zakrzewski, 1987):

Task 1: Description of Soviet investigations of ship icing;

Task 2: Examination of the ship parameters used in the Soviet data collection program;

Task 3: Investigation of data on splashing ships with collision-generated spray;

Task 4: Investigation of the occurrence of icing events on ships;

Task 5: Examining the raw data on ice growth rates on ships;

Task 6: Investigation of ice loads on ships;

Task 7: Investigation of physical properties of the ice accreted on ships;

Task 8: Preparing the final report.

The detailed description of these research tasks is given in our unsolicited proposal (Lozowski and Zakrzewski, 1987).

The research was initiated on June 1, 1987, and was completed on November 30, 1987. During the work on the project, two progress reports were produced and submitted to Mr. Ross Brown of AES.

2. DESCRIPTION OF THE SOVIET INVESTIGATIONS OF SHIP ICING

The icing of ships appears to have a tremendous impact on several aspects of the Soviet economy and exploration of its natural resources, especially in the Arctic and in the cold seas around the North Pacific Ocean. Maintaining the Great Northern Sea Route ("Glavnaya Severnaya Morskaya Put") that connects the Soviet ports of the Atlantic and Pacific coasts through the cold seas of the Soviet Arctic (Barents, Kara, Laptiev, East Siberian and Chukchi seas) challenges a large fleet of powerful polar-class icebreakers which break polar pack ice all year round. It also results in exposing ships operating there to superstructure icing. During the open-water season (July-September) ships operating along the Great Northern Sea Route are prone to spray icing. During the rest of the year they are affected by atmospheric icing due to supercooled fog (Figs 2.1 and 2.2).

Icing of Soviet ships in the Arctic seas has been reported since operations were started there in the early 1930s. Although no icebreakers or cargo vessels have sunk in the Arctic due to icing, a few of them have experienced "dramatic situations" when spray was freezing on them. Some ships have been nearly lost due to diminished stability (Panov, 1976; Aksyutin, 1979). Complete disasters have been avoided, however, by sheltering the icebreakers in ice fields where spraying of the ships ceased.

Icing is even more severe in the cold seas beyond the Arctic Basin. Many Soviet cargo vessels and thousands of Soviet fishing vessels operating in the cold seas around the North Pacific and North Atlantic oceans have experienced icing. It should be noted that there

Fig. 2.1. Icing of the icebreaker "Murmansk" due to evaporation from the sea surface in the Kara Sea in January 1973 (Panov, 1976).

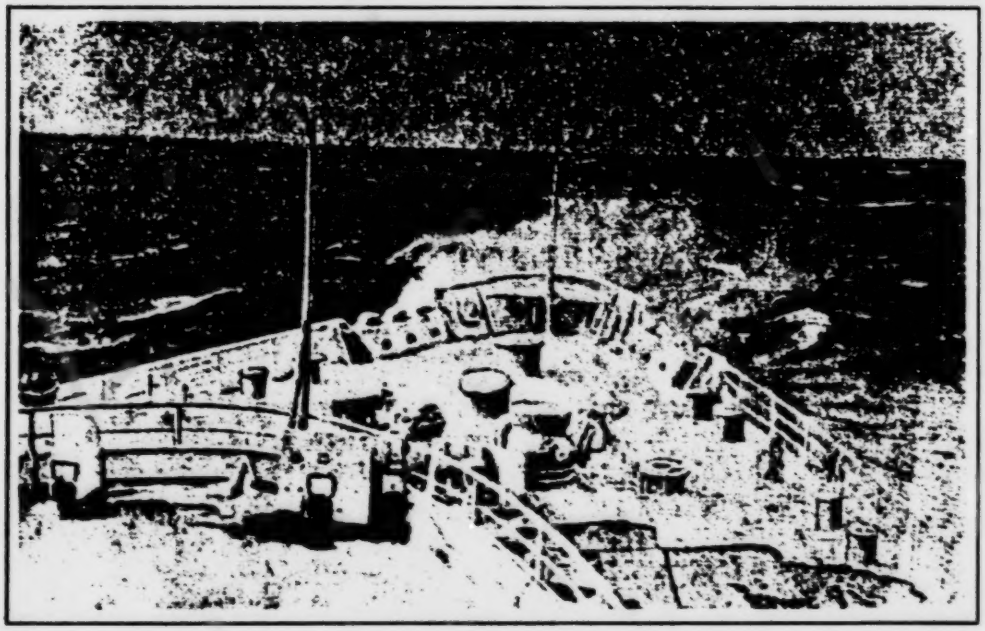

Fig. 2.2. Spray icing on the nuclear-powered icebreaker "Lenin" in the Barents Sea on 26 January 1973 (Panov, 1976).

are in the USSR several hundred ocean-going fishing vessels which are rather small (of length 40 m or less). Since these ships (Fig. 2.3) are sent to cold oceans in great numbers with no regard to the season and weather conditions*, many of them have been lost. According to Buyanov et al. (1975), sixteen Soviet vessels capsized in the Northwest Pacific due to icing between 1956 and 1972. Based on a careful search of all the available literature, we have evidence that up until 1966, the ships operating in cold seas were not provided with ship icing forecasts or icing warnings (Panov, 1976). This situation prevailed even though the Soviet fishing vessels were operating in huge groups consisting sometimes of several hundred ships as reported by Buyanov (1971a) for the Sea of Okhotsk. When an icing storm develops, it hits the ships, unless they are alerted and some protective measures (mainly to leave the area and to shelter in the lee of land) are taken quickly. Unfortunately, when the ships are taken by surprise by a severe icing storm or if shelter is far away, they can accumulate a lot of ice and

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*Buyanov (1971a) shows that there was a planned reduction of the Soviet fishing fleet operating in the Sea of Okhotsk, as the weather conditions worsened during the winter. The vessels of smaller size (more vulnerable to severe icing) were temporarily taken out of service, and only the large fishing vessels were left in service. However, based on information about icing related disasters in the Soviet fishing fleet (Aksyutin, 1979; Panov, 1976; Shellard, 1974; Tsoy, 1968), one can deduce that such planned preventative action must have been instituted only in the late 1960s. Prior to this time, several small ships were lost due to icing in the middle of winter when the sea surface temperature and air temperature were low enough to result in very heavy accretion on small ships.

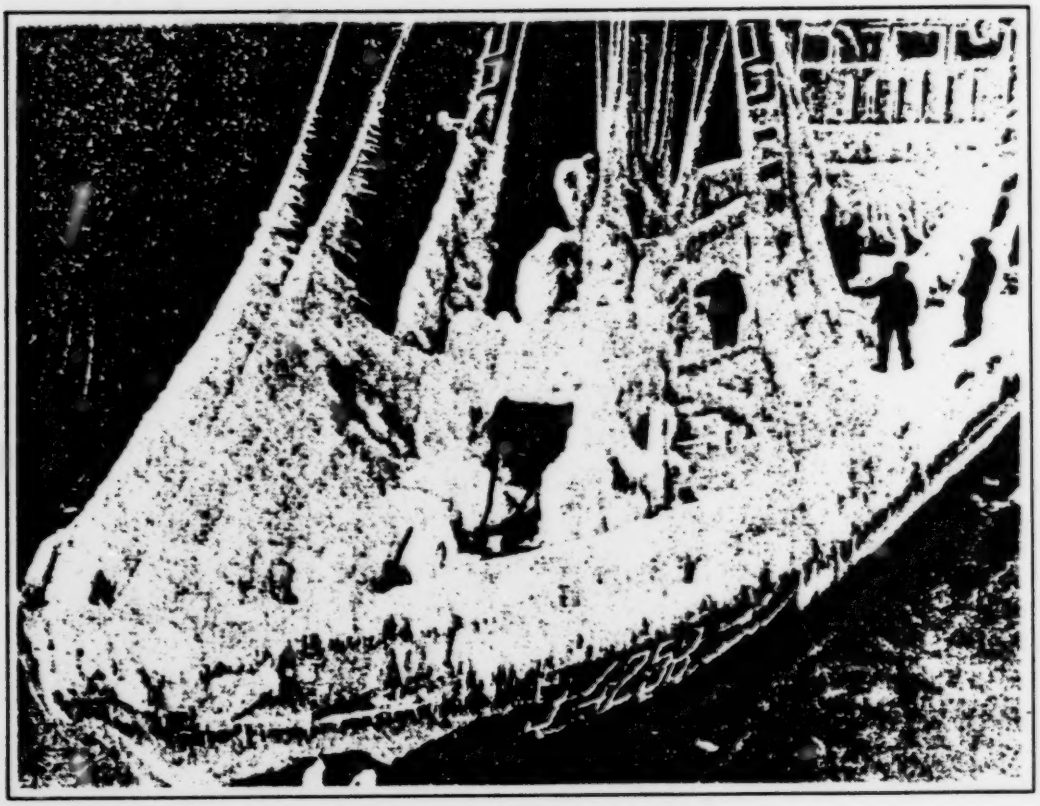

Fig. 2.3. The MFV "Piarnu" on return to Tallin from the cold Baltic Sea in 1969 (Aksyutin, 1979).

sink. On one occasion, ten fishing vessels capsized due to ice loads during an icing storm in the North Pacific Ocean (Shellard, 1974; Aksyutin, 1979). On January 25, 1965, six Japanese and four Soviet fishing vessels were lost due to icing in the eastern part of the Bering Sea. The Soviet medium-sized fishing vessels (MFVs) which sank were (Shellard, 1974; Tsoy, 1968; Aksyutin, 1979): "Boksitogorsk", "Sievsk", "Siebeizh", and "Natchitchevan". Although the Soviets had already experienced several ship losses due to icing, this disaster to four of their vessels on one occasion was shocking both to the Soviet government and to public opinion* (Netchaev, 1967). It resulted in the launching of a government-controlled program for the investigation of ship icing (Panov, 1976). The main objective of this program was to increase the safety of fishing vessels operating in cold oceans, and to work out satisfactory techniques for forecasting ship icing and removing ice from the ships. Moreover, the disaster of the above fishing vessels resulted in the establishment of a ship icing forecast service (sluzba prognozov obledenyeya sudov) in the USSR in 1966 (Panov, 1976; Temporary guidance for ship icing warning, 1969).

Since in the Soviet Union all fishing vessels are state-owned and operate under the superior jurisdiction of the Ministry of Fisheries of the USSR, this ministry was evidently concerned about the need for taking all possible measures to improve the safety of fishing vessels, especially those most prone to superstructure icing and

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*Information about this disaster was released to the press and the nation-wide newspaper "Pravda" criticized the weather services for not considering icing as an environmental hazard.

capsizing due to icing. This interest was followed up by questioning (Buyanov, 1968, 1971a, 1971b; Kultashev and Panov, 1970) the seaworthiness of the most common Soviet ocean-going fishing vessels, known as medium-sized fishing vessels (see page 19 and Table 3.1). MFVs were found to be the most vulnerable to heavy icing (Fig. 2.3). Vessels of this type were in fact already well-known for their loss of stability in icing. This had resulted in the preparation of a special guide (Eydel'man, 1963) for the crew, which listed several measures to improve ship stability during an icing event. This guide was published three years before the ship icing forecast service was established in the USSR (1966).

According to Sharapov and Karpushin (1983), the Ministry of Fisheries of the USSR, from 1967 to 1972, conducted a major interdisciplinary research program, targetted at studying the physical processes associated with the icing of MFVs. The Ministry of Fisheries initiated the launching of several ship surveys aimed at the collection of field data on the icing and spraying of fishing vessels. Several fishing vessels (medium-sized fishing vessels and medium-sized freezing trawlers) were recalled from service by the Ministry of Fisheries and promptly prepared for research cruises.

The research program to study ship icing was established at the Arctic and Antarctic Research Institute (Arkticheskii i Antarkticheskii Nauchno-Issledovatiel'skii Institut, AANII) in Leningrad. This occurred because the Ministry of Fisheries requested the Central Committee for the Hydrometeorological Service of the Government of the USSR (Glavnoye

Upravlenye Gidrometeorologicheskoy Sluzby pri Soviete Ministrov SSSR) to provide it with close collaboration and expertise from AANII on ship icing (since AANII works under the jurisdiction of the above committee for the Hydrometeorological Service). Several regional branches of the Central Hydrological and Meteorological Institut (Centralnii Gidrologicheskii i Meteorologicheskii Institut) of the above committee also joined the program. The list of authors of the Soviet reports on ship icing, dedicated especially to ship icing forecasting, indicates that the Leningrad and Vladivostok branches of the Central Hydrological and Meteorological Institute contributed most to the research. In addition, we were able to find that the Leningrad Branch of the National Oceanographical Institute (Leningradskoye Otdelenye Gosudarstviennogo Instituta Okeanografii) was also active in research on the forecasting of ship icing (Buyanov et al., 1975).

Since the ships were scheduled for the field data collection program, the Soviets had to produce original measurement equipment for the recording of icing-related parameters (e.g., ice growth rates, ice loads, adhesive strength of the accretion, etc.). At that time there were no such devices available. Recently published Japanese reports on ship icing (e.g., Tabata et al., 1963) contained much valuable information on the methodology of the Japanese measurements of icing-related parameters (e.g., measuring paper sheets embedded in the ice accretions on various ship components was a Japanese technique for estimating ice growth rates). The Soviets designed several simple innovative and unique techniques for the measurement of ice loads and icing rates. Moreover, apparatus for the measurement of various physical parameters of the

accretions was prepared as well. Detailed information on these devices is given in volumes 298 and 317 of Trudy AANII, a journal routinely issued by the Arctic and Antarctic Research Institute (e.g., Panyushkin and Rozenberg, 1972; Panyushkin et al., 1972; Panyushkin and Petrov, 1975). Since the technical details of these devices are beyond the scope of this report, we will not provide any specific data about the measurement systems. However, when we describe the data sets (chapters 4, 6-8), a brief description of the method/technique used for the measurements will be given in the introduction to each of these chapters. Here, we simply note that most of the measurement methodologies and devices were prepared by Dr. A.V. Panyushkin from the Arctic and Antarctic Research Institute. Some of them were produced in collaboration with Leningrad Technical University (Leningradskii Politekhnicheskii Institut imenii M.I. Kalinina) (Panov, 1976).

The State University of Moscow, Research Snow and Avalanche Laboratory (Problemnaya Laboratoriya Sneznich Lavin Moskovskogo Gosudarstviennogo Universiteta) joined the program soon after it had started (Panov, 1976).

The Moscow scientists were mostly interested in the laboratory simulation of ship icing and in the investigation of the mechanical and chemical properties of the accretion. In the late 1960s some research institutes of the Ministry of Chemical Industry (Ministry Chemicheskovo Promysla) of the USSR were also involved in this major project. These institutes were responsible for the preparation and production of several experimental surfaces (paints, mats, shields) of very low adhesion. This was aimed at preventing Soviet ships from icing through

the use of ice-phobic materials. However, we are unable to give any detailed information on these research centres.

The research program was supervised by Professor Ye. Borisenkov from AANII and Drs. Panov, Panyushkin and Shvayshteyn from AANII. The guidance for laboratory and field observations for the measurement of icing-related parameters and for the production of the measuring equipment was provided by Dr. A.V. Panyushkin (AANII) who himself constructed several of the devices (Panov, 1976).

Probably the most detailed information on the overall structure of the Soviet investigations of ship icing has been given by Borisenkov and Panov (1972) and Panov (1976). They listed several principal objectives of the Soviet research on ship icing and also proposed a framework for future research. The investigations of ship icing in USSR in the 1960s and 1970s included (Borisenkov and Panov, 1972; Panov, 1976):

(1) Statistical investigations of hydrometeorological conditions under which the icing of ships takes place, to collect and generalize data, and to create navigational and forecasting aids for the hydrometeorological service to navigation under icing conditions.

(2) Field studies of icing conditions and of the nature of this phenomenon and tests of icing control devices under various hydrometeorological conditions at sea.

(3) Laboratory studies of icing conditions and tests of some control devices in special refrigeration chambers.

(4) Theoretical investigations of the growth of ice on a ship under various hydrometeorological conditions, to develop a physical theory of this process, determine the stability of ships during icing, and develop numerical methods for forecasting given icing conditions.

Table 2.1. Compiled data on the Soviet field ship surveys performed under the USSR Ministry of Fisheries data collection program.

Date	Sea	Ship	Objective of the measuring program	Reference
Feb 1968	Japan Sea	"Academic Ber" (MFV)	Icing rates; ice loads due to icing, physical, mechanical and chemical properties of the accretion; frequency of spraying of the ship	Gurvitch 1972 Golub'iev 1972 Panov 1976
Mar 1968	Barents Sea	MFT "Aland"	Icing rates; ice loads; ship stability, frequency of spraying; ship behavior in heavy seas	Aksyutin 1979 Gurvitch 1972 Rozenberg 1971
Mar 1968	Unknown*	"Murmanchanin" (seiner)	Splashing of the ship with spray; ship response to waves; ship stability under conditions of icing	Rozenberg 1971
Apr 1968	Barents Sea	MFV "Academic Knipovitch	Ship response to waves; frequency of spraying of the ship	Rozenberg 1971
Apr 1968	Barents Sea	R/V "Polyarnik"**	Ship response to waves, splashing the ship with spray; icing rates and ice loads due to icing	Rozenberg 1971 Gurvitch 1972
Jan-Feb 1969	Baltic Sea	MFV "Piarnu"	Icing rates; ice loads; effect of ice loads on ship stability; mechanical properties of the accretion; general study of conditions of ship icing in the Baltic	Rozenberg 1971 Gurvitch 1972 Rybnikov 1975 Panov 1976 Aksyutin 1979
Jan-Feb 1969	Japan Sea	"Academic Ber" MFV	The same as in 1968	Panov 1976
Jan-Feb 1969	Barents Sea	"Professor Somov" MFV***	Splashing of the ship with collision-generated spray; ice growth rates and ice loads due to icing; ship stability; salinity of the accretion; de-icing and anti-icing	Rozenberg 1971 Gurvitch 1972
Aug-Nov 1969	North Atlantic Oc.	MFV "Iceberg"**	Splashing of the ship with collision-generated spray	Rozenberg 1971 Borisenkov & Panov 1972

cont'd...

Table 2.1 continued:

Date	Sea	Ship	Objective of the measuring program	Reference
Jan 1970	Barents Sea	"Professor Somov" MFV	de-icing and anti-icing	Panyushkin et al. 1972a
1971	Bering Sea	MFT "Pogranichnik Dergach"	Icing rates and ice loads on the MRT; performance of the ship icing forecast	Buyanov et al. 1975
Feb 1972	Bering Sea	MFT "Pogranichnik Zveyev"	Icing rates and ice loads on the MRT; performance of the ship icing forecast	Buyanov et al. 1975
1973****	Japan Sea	MFV "Narva"	The measurement of the spray cloud parameters, de-icing (Feb. 1973)	Borisenkov et al. 1975 Panov et al. 1975a

* Probably in the Bering Sea.

** This is a research vessel owned by AANII

*** This trawler was completely rebuilt for the purpose of the research cruises

**** This study was performed after the completion of the main research program sponsored by the USSR, Ministry of Fisheries

A detailed search of the Soviet literature on ship icing has led to the list of field expeditions for the investigation of ship icing in Table 2.1. To the best of our knowledge this table points out that the Soviet program for icing data collection was the largest ever launched. Based on our review of all available reports we estimate that more than 50 scientists participated in the field program, while many others were working exclusively on land.

3. BASIC INFORMATION ON THE PARAMETERS OF THE SHIPS PARTICIPATING IN THE SOVIET FIELD DATA COLLECTION PROGRAM

There are no available ship design plans for the vessels participating in the Soviet field program. Fortunately, from miscellaneous sources we have obtained the following information about the basic parameters of these vessels.

(a) Medium-sized seiner (srednii rybolovnii seyner RS-300) - overall length approximately 30 m; deadweight 200-240 tonnes, crew - 12 (Panov, 1976; Tyurin, 1970).

(b) Medium-sized fishing vessel, MFV (srednii rybolovnii travler SRT) - overall length approximately 40 m, deadweight 430-460 tonnes; crew - 25-26 (Panov, 1976; Tyurin, 1970).

(c) Medium-sized freezing trawler*, MFT (srednii rybolovnii morozitiel'nii travler, SRMT) - overall length 54 m, deadweight 902 tonnes.

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*The Soviets used MFTs of the "Mayak" type in their data collection program.

There are very few photographs and figures of these ships. A general side view of an MFV is shown in Fig. 3.1. A more detailed plan of the deck of an MFV is shown in Fig. 3.2. This figure shows the location of several measurement devices installed on the research vessel "Professor Somov", used for the collection of field data on several icing-related parameters (Panov, 1976; Gurvitch, 1972). There are no photos or figures available of an MFT. Fortunately, some valuable information is given by Aksyutin (1979) who listed the basic parameters of several of the ships participating in the Soviet data collection program (Table 3.1). Among others, three medium-sized freezing trawlers ("8434", "8482", and "Aland") are included in this table. Besides having larger dimensions, MFTs have a maximum speed greater than that of MFVs.

4. SPLASHING OF SOVIET SHIPS WITH SPRAY

4.1. Wind-generated Spray

Soviet fishing vessels are prone to spray icing due to splashing with collision-generated spray. Wind-generated spray blown off the wave crests by strong wind does not significantly affect them even in high seas. All Soviet authors were united in stating that collision-generated spray is the cause of the most dangerous icing, but no one reported wind-generated spray as an exclusive cause of ship icing. However, in Aksyutin (1979) several exhaustive descriptions of ship disasters due to superstructure icing are given. For ships which are listing heavily due to ice loads on one side, especially when the ship

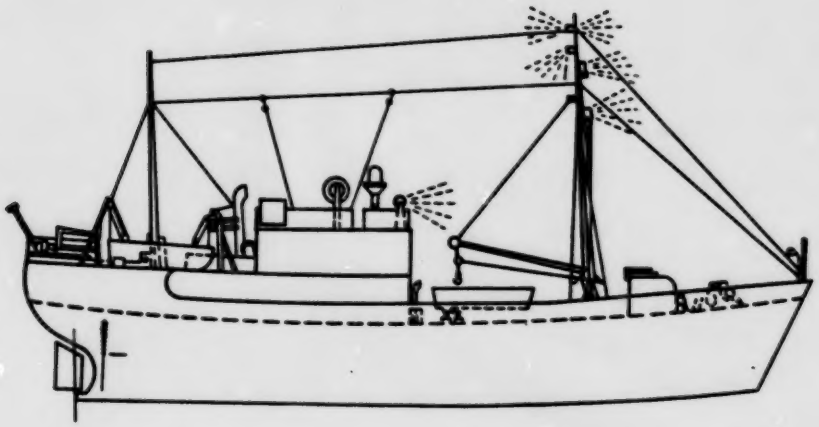
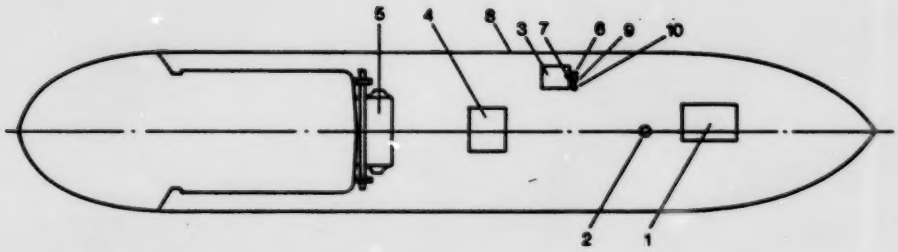


Fig. 3.1. Side view of an MFV (Aksyutin, 1979).



1-hatch to the forepeak, 2-mast, 3-exit from the lab, 4-hatch of the cargo compartment, 5-winch, 6-thermocouple in the accretion, 7-thermocouple, 8-thermometer for the water, 9-thermometer for the air, 10-thermometer for the accretion.

Fig. 3.2. The deck of the MFV "Professor Somov" with location of the measuring equipment shown (Panov, 1976).

Table 3.1. Basic parameters of the ships participating in the Soviet field data collection program (Aksyutin, 1979).

Ship	Overall length (m)	Breadth (m)	Free-board (m)	Dead-weight (tonnes)	Maximum speed* (knots)
MFV "Academic Ber"	39.5	7.3	3.5	446	9
MFV "Piarnu"	39.2	7.3	3.5	462	9
MFV "Iceberg"	39.2	7.3	3.5	418	8
MFV "Polyarnik"	38.5	7.2	3.5	456	9
MFV "Professor Somov"	39.2	7.3	3.5	459	8
SRTM - 8434	54.2	9.3	6.0	899	12
SRTM - 8482	54.2	9.3	4.7	937	11
SRTM "Aland"	54.2	9.3	4.7	908	12
r/v "Mayak"	39.0	7.0	5.0	800	9
m/s "Bditel' nyi"	56.5	11.5	5.6	1460	13.4

*1 knot = 0.514 m s^{-1}

has lost manoeuverability and is lying along the wave crests in high seas, wind-generated spray may contribute to the delivery of water. But it certainly is not a major cause of icing, especially at the beginning of an icing event. The data of Preobrazhenskii (1973) on the wind-generated spray collected on board a ship in low and in moderate to high seas, show that the liquid water content (LWC) in wind-generated spray is one to three orders of magnitude smaller than that for collision-generated spray produced under the same air-sea conditions (Borisenkov et al., 1975b; Zakrzewski, 1987). The Preobrazhenskii (1973) data are given in Fig. 4.1.

The vertical distribution of the LWC in wind-generated spray is described by the formula (Preobrazhenskii, 1973):

$$w(z) = w_o \exp\left(-\beta\left(z - \frac{H}{2}\right)\right) \quad \text{kg m}^{-3} \tag{4.1}$$

where z is the height (in m) above the water surface, H is the wave height (in m), and w_o and β are constants, empirically found for various wind speeds to be:

$$w_o = 10^{-7} \text{ kg m}^{-3} \text{ and } \beta = 0.35 \text{ for wind speed 7-12 m s}^{-1}$$
$$w_o = 10^{-5} \text{ kg m}^{-3} \text{ and } \beta = 1.00 \text{ for wind speed 15-25 m s}^{-1} \tag{4.2}$$

4.2. Collision-generated Spray

Collision-generated spray is the most common cause of the icing of ships (see Table 5.1) as reported by several Soviet investigators (e.g., Shekhtman, 1967, 1968; Panov, 1976). The Soviets were aware of this fact and conducted several detailed measurements of (1) the zone

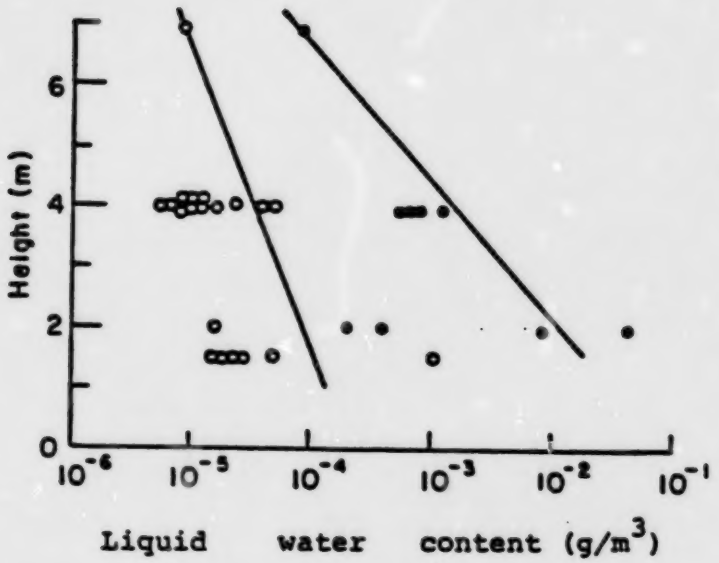


Fig. 4.1. The liquid water content in wind-generated spray as measured on a ship (Preobrazhenskii, 1973).

of spraying of a ship, (2) the frequency of spraying of a ship, (3) the liquid water content and droplet spectral size distributions. An overview of the Soviet reports leads to the conclusion that the general objective of the above measurements was the estimation of the spray fluxes to the ship.

4.2.1. Estimation of the zone of spraying on a vessel

The zone of splashing of a ship with a cloud of collision-generated spray has been estimated for several wind speeds. Only MFVs were investigated. There is no available information on the zone of spraying of Soviet MFTs. Presumably, this is because the Soviets did not choose to concentrate on MFTs which were known to be less prone to icing and less vulnerable to the loss of stability due to icing.

Medium-sized fishing vessels (Fig. 2.3) were found not to be affected by collision-generated spray (hereafter, spray) in winds up to 5 m s^{-1}. Based on several observations, Kultashev and Panov (1970) found that the minimum wind speed permitting the development of waves large enough to splash the deck (or any other ship component) of an MFV is 5-6 m s^{-1}. For such a wind speed, the significant wave height is about 0.9 m for a fetch of 200 nautical miles. The Beaufort scale also shows that winds of speed of 5-6 m s^{-1} generate waves 0.6 to 0.9 m high.

In winds higher than 5-6 m s^{-1}, spray hits an MFV. However, the threshold wind speed that results in spraying of the ship deck is equal to about 8.0 m s^{-1} as shown by Sharapov (1971a, Table 1). Sharapov reported that for MFVs moving into the waves with a heading

from 180° to 120°, spray splashes up to half of the ship deck and the lower part of the mast and rigging (Table 4.1). The data of both Kultashev and Panov (1971) and of Sharapov (1971a) are correlated pretty well, because for wind speeds from 5-6 to 8 m s^{-1}, icing can progress on an MFV but its extent is limited only to the bulwarks (both sides) and to that part of the ship which is wetted by water flushing through the scuppers. It is interesting to note that an independent source of information on the icing of vessels (Smirnov, 1972) supports a separate consideration of the conditions resulting in ice accretion on the ship hull, and of those resulting in icing of the ship superstructure. Smirnov (1972) stated that hull icing occurs in cold air when the wind speed, U_{10}, exceeds 8.2 m s^{-1}, while superstructure icing occurs when U_{10} exceeds 8.5 m s^{-1}. The differences between the threshold wind speeds resulting in the icing of the ship hull and superstructure for an MFV and the corresponding threshold for the ships considered by Smirnov (1972) result from the fact that Smirnov based his criteria on the American data given in the Oceanographic Atlas of Polar Seas (1958), and evidently American vessels differ considerably from Soviet MFVs.

The availability of field observations permitted Buyanov (1971c) to produce a special scale for the estimation of the extent of the spraying of an MFV. However, this scale does not correlate the zone of spraying with the wind speed, as shown by Sharapov (1971a). Rather it correlates the frequency of the splashing of the ship by spray with the extent of the spraying zone (Table 4.2). Although one cannot at first glance see any obvious reason for such a correlation,

Table 4.1. The relationship between the extent of the spraying zone over an MFV and the wind speed (Sharapov, 1971a).

Wind speed in Beaufort ($m\ s^{-1}$)	Frequency of splashing the ship (min^{-1})	The extent of the spraying zone over the ship
5°B (8.0-10.7)	2-4	Front half of the deck, lower part of the mast and rigging
6°B (10.8-13.8)	3-6	Up to 3/4 of the height of the mast and rigging*; entire ship deck; spray reaches the front face of the superstructure
7°B (13.9-17.1)	5-8	Entire deck; entire front face of the superstructure; entire rigging and mast; spray reaches the deck of the superstructure
8°B (17.2-20.7)	9-11	Entire deck; entire mast and rigging; entire ship superstructure; lifeboat deck
≥10°B (≥24.5)	≥11	The entire vessel

*The height of the mast of an MFV is approximately 10.0-10.5 m; the height of the rigging is approximately 7.5-8.0 m.

Table 4.2. A scale for the estimation of the extent of the spraying zone on an MFV (Buyanov, 1971c).

"Buyanov" degree (°C)	Frequency of spraying the ship (min^{-1})	The extent of the spraying zone
1	-	Calm
2	-	Spray does not impinge on the ship deck (but it is generated*)
3	1-4	Spray hits the ship deck from time to time
4	4-5	Spray hits the foredeck, lower parts of the forecastle and rigging
5	6-7	The entire deck, half of the ship mast and rigging
6	7-8	The entire deck; half of the ship mast and rigging; the spray reaches the front face of the ship superstructure up to the windows of the wheelhouse
7	8-9	The entire deck, mast and rigging; the entire face of the ship superstructure
8	9-10	The spray hits the entire ship superstructure and the wheelhouse (and deck and rigging as well*)
9	10-11	The spray flies over the wheelhouse reaching the lifeboat deck
10	≥11	The spray flies over the entire vessel (it should read: the entire vessel is sprayed*)

*Our comments

we have deduced that Buyanov (1971c) was right to propose such a scale. First, the extent of the spraying zone over a ship depends, inter alia, on the wave height. Since the significant wave height for a fully-developed sea and a given fetch can be determined using the wind speed, there is a relationship between the extent of the spraying zone and the wind speed. Second, the wavelength also depends on the wind speed. This relation can be deduced from the relationships between the period of the waves and the wind speed, and between the period of the waves and their phase speed (Pierson et al., 1955). Since ship-wave collisions occur when the ship crosses the wave crest, the frequency of these collisions should depend on a spectrum of wavelengths of the waves generated under given conditions, and consequently, on the wind speed. It should be emphasized that navigators on most ships don't have any accurate techniques for the estimation of wave height. An experienced navigator can give a visual estimate, but this is still only a rough guess. However, one can easily measure the frequency of spray cloud generation by a ship. This can be easily done by simply recording how many such spray clouds are generated over a specified time interval (e.g., 1 minute). This practical approach was considered by Buyanov (1971c), who, fortunately, was an ocean-going ship master. The possibility of employing the above scale for the estimation of the total icing rate on the entire MFV will be discussed in Chapter 6. Panov (1971) claimed that the scale given by Buyanov (1971c)(Table 4.2) is not precise, and contains an error because for the 10th degree, Buyanov proposed the description "the spray flies over the entire ship" rather than "the entire ship is sprayed." The

latter would appear to be more proper. Moreover, Panov gave his own scale (Panov, 1971, 1976 - Appendix 1) which was claimed to give "satisfactory results" for MFVs, MFTs, and MRTs. However, it is a pity that this scale (Table 4.3) does not give any relationship between the weather (or oceanographic conditions) and the extent of the spraying zone. This scale has one limitation: the ship should be moving into the waves with a heading of 180-135°.

The above scales for the extent of the spraying zone on a ship can be supplemented by an interesting data set of Kuznietsov et al. (1971). The maximum extent of the spraying zone over the ship can be deduced from the data on the upper limit of the accretion, if the ship is sailing under icing conditions. Kuznietsov et al. (1971) listed the height of the upper limit of the accretion on the foremast of an MFV (see Fig. 3.1), along with the mean frequency of the spraying, the range of the spraying frequencies, the ship heading, and the mean speed of the relative wind (Table 4.4). The relationship between the mean relative wind speed and the height of the upper limit of the accretion on the foremast of an MFV is shown in Fig. 4.2. However, we doubt whether there is such a relationship as claimed by Kuznietsov et al. (1971). The empirical points in Fig. 4.2 indicate that a height of upper limit of the accretion changes very little with a relative wind speed, if at all. Zakrzewski (1987) argued that the only relationship between the height of the spraying zone and the air-sea and ship motion parameters is that between the height of the spraying zone and the ship speed relative to waves. Very recently, the extent of the spraying zone on an MFV has been modelled in Canada (Zakrzewski et al., 1987a). This ship spraying model has been loaded with the field data on the extent of the spraying zone over an MFV as listed

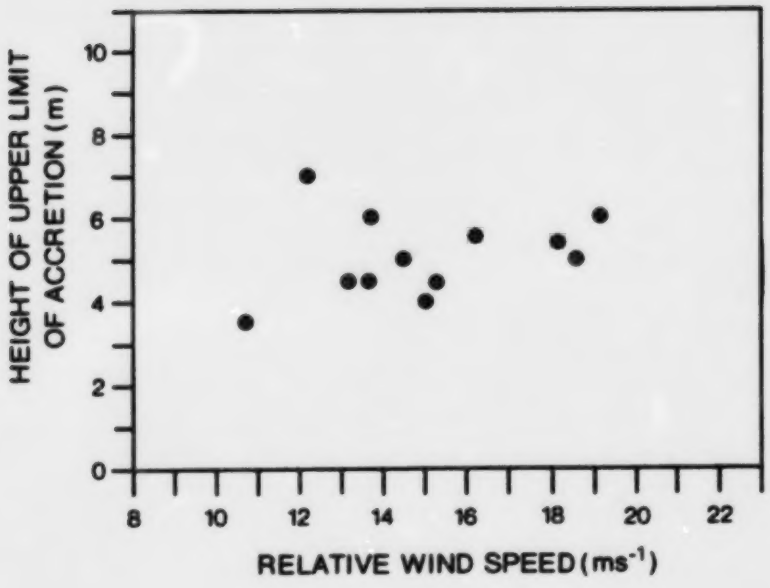


Fig. 4.2. The relationship between the relative wind speed and the height of the upper limit of the ice accretion on the foremast of an MFV (replotted from Kuznietsov et al., 1971).

Table 4.3. The scale for the spraying of MFVs, MFTs, and MRTs (Panov, 1971, 1976).

"Panov" degree (°)	Description of the spraying zone
0	The spray does not reach the deck
1	The spray hits 1/4 of the length of the bow part of the ship
2	The spray hits 1/2 of the length of the bow part of the ship, the lower part of the mast and rigging
3	The spray hits the entire ship deck up to the front face of the superstructure, and the lower half of the mast and rigging
4	The entire deck; 3/4 of the mast and rigging; the front face of the superstructure - up to half its height
5	The entire deck of the ship and the entire front face of the superstructure
6	The entire deck, mast, rigging, the front face of the superstructure and the wheelhouse
7	The entire deck, rigging, mast, ship superstructure, the wheelhouse, and half of the lifeboat deck
8	The entire vessel

by Sharapov (1971a) and Kuznietsov et al. (1971). For this purpose the data set of Kuznietsov et al. (1971) given in Table 4.4 has been modified in order to obtain the wind speed (true wind) and the ship speed for each icing event reported by the Soviets. This is because the model of Zakrzewski et al. (1987a) uses the speed of the true wind and the ship speed rather than the relative wind speed that was listed by the Soviets. For the maximum ship speed that can be maintained by an MFV, under a given wind speed and heading (Table 4.5), the modified data set of Kuznietsov et al. (1971) is shown in Table 4.6. The modelled extent of the spraying zone over an MFV is shown in Fig. 4.3.

4.2.2. The frequency of spraying of a ship

There are several sources of data on the frequency of spraying of Soviet vessels. Most of the data concerns MFVs; fortunately, however, there is some data for MFTs available in Kultashev et al. (1972).

Based on the results of several field observations, conducted in the Japan, Baltic, and Barents seas, the effects of the wave height and ship heading (Fig. 4.4) and of ship speed and heading (Fig. 4.5) on the frequency of spraying an MFV and an MFT have been found. The frequency of spraying of the ship is largest for a ship heading of 155-140°, but the effect of the ship speed is also noticeable (Fig. 4.5). As the ship speed increases, the ship heading, which results in the maximum frequency of spraying of the ship, decreases. However, since the data shown in Fig. 4.5 were collected in moderate seas (wave height 2.0-2.5 m; wavelength 20-25 m (Kultashev

Table 4.4. The relationship between the height of the upper limit of the accretion on the foremast of an MFV, the frequency of spraying of the ship, the ship heading, and the mean relative wind speed (Kuznietsov et al., 1971).

Mean frequency of spraying (min^{-1})	Range of spraying frequency (min^{-1})	Ship heading* (deg)	Mean relative wind speed ($m\ s^{-1}$)	Height of accretion upper limit on foremast (m)
2.5	2-3	20-30	10.7	3.5
3.2	2-4	0-7	13.2	4.5
3.2	1-7	5-166	15.2	4.5
4.3	3-7	5-30	13.6	4.5
4.5	2-7	3-30	16.2	5.5
4.5	3-7	29-39	13.7	6.0
5.3	5-6	9-25	14.5	5.0
5.8	1-11	31-94	12.2	7.0
5.8	1-11	5-15	18.6	5.0
6.2	4-8	5-166	18.2	5.5
6.3	4-10	0-130	15.0	4.0
8.0	7-9	5-35	22.2	6.5
9.0	6-11	15-25	19.1	6.0

*Kuznietsov et al. (1971) used the ship heading calculated from 0° for the ship moving into the waves and 180° for the ship moving downwind. In our report, we use a value of 180° for the ship heading for a ship moving 'precisely' into the waves and 0° for a ship moving with the waves.

Table 4.5. Postulated maximum speeds of ship operation for an MFV of Soviet type while not trawling fishing nets (Zakrzewski et al., 1987a).

Ship heading (deg)	Wind speed ($m\ s^{-1}$)						Plan view
	5	10	15	20	25	30	
180	4.5	3.9	3.4	2.5	1.5	≤1.0	A
170-160	4.5	3.9	3.4	2.5	1.5	1.0	B
150-130	4.5	4.0	3.5	2.7	2.0	1.5	C
120-100	4.6	4.5	3.5	3.2	2.5*	2.0*	D
90	4.6	4.5	3.5	3.2	2.7*	2.5*	E

*Ship heading not recommended for vessels with heavy ice loads due to icing.

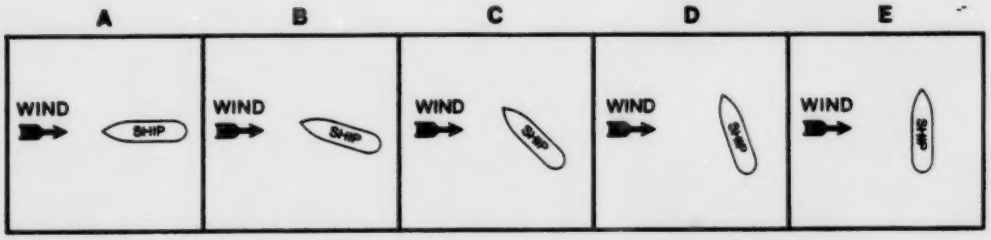


Table 4.6. Basic air and ship motion parameters reconstructed by Zakrzewski et al. (1987a) for 13 documented cases of ship icing listed in Kuzniecov et al. (1971).

No.	Wind speed* ($m\ s^{-1}$)	Ship speed* ($m\ s^{-1}$)	Ship heading (deg)	Height of upper limit of accretion on the foremast (m)
1	7.0	4.0	150	3.5
2	10.2	3.0	180	4.5
3	12.6	3.0	150	4.5
4	10.6	3.0	175	4.5
5	13.6	2.6	180	5.5
6	12.2	2.5	165	5.0
7	10.2	4.0	145	6.0
8	10.9	4.5	105	7.0
9	16.6	2.0	180	5.0
10	16.2	2.0	180	5.5
11	14.5	2.0	100	4.0
12	21.2	1.0	170	6.5
13	17.2	2.0	165	6.0

*Approximated using the raw data on ship heading and relative wind velocity given in Kuzniecov et al. (1971).

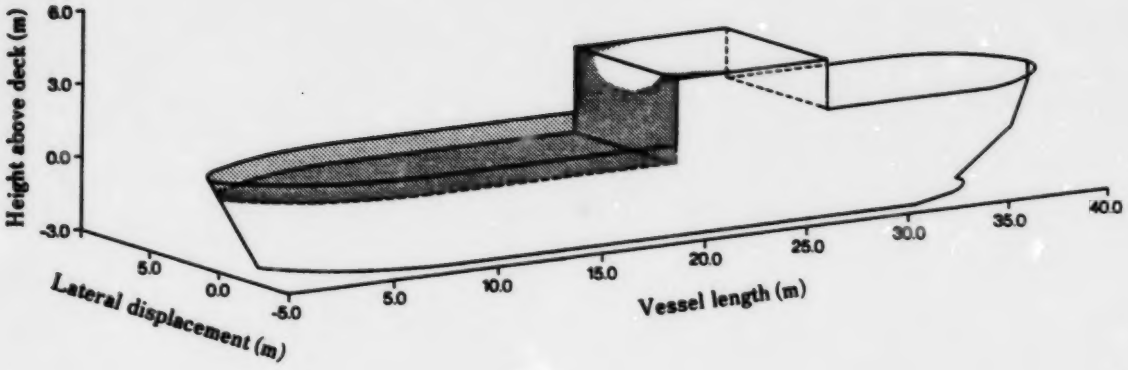


Fig. 4.3. The wetted surface of a medium-sized fishing vessel for a wind speed of 15 m/s, a ship speed of 2 m/s, and a ship heading of 180°. The fetch is assumed to be equal to 200 nautical miles (Zakrzewski et al., 1987a).

et al., 1972)), one can not draw general conclusions for all oceanographic conditions. Figure 4.4, describing the effects of the ship heading and the wave height on the frequency of spraying of a ship, clearly shows that the ship heading corresponding to the maximum frequency of spraying changes from 165° for high waves to ≤140° for lower waves. Aksyutin (1979) and Panov (1976) state that, for MFTs, the maximum frequency of spraying of the ship occurs with a ship heading of 100-110°, when the ship moves almost parallel to the wave crests. The data set listed in Panov (1971) shows that the frequency of spraying of an MFV depends on wave length, ship speed and ship heading (Table 4.7). However, it should be noted that the spray does not splash the ship for every ship-wave collision. On average, the ship is splashed by every other spray cloud generated by the ship-wave interaction.

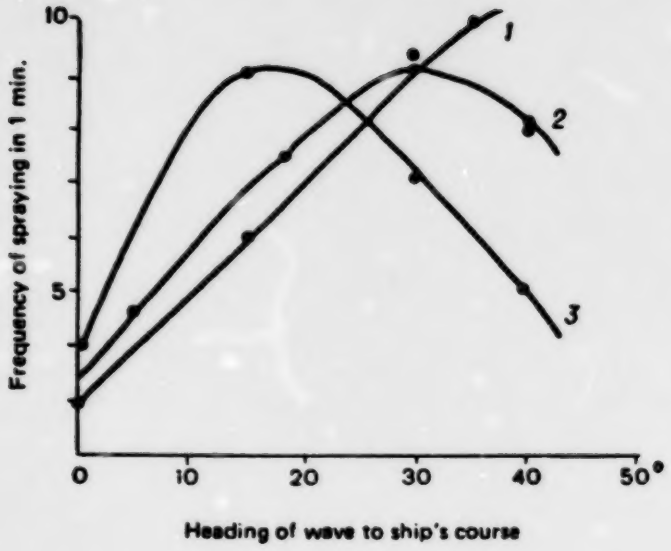
Panov (1971) proposed the following empirical formula for the frequency of spraying of an MFV

$$n = 15.78 - 18.04 \exp(-4.26/P_r) \quad \text{min}^{-1} \tag{4.1}$$

where P_r is the time interval (in s) between two successive ship-wave collisions. Formula (4.1) is valid for $3.5s \leq P_r \leq 15.0s$ (Panov, 1971). P_r can be calculated using the ship speed V (in m s^{-1}), the ship heading α (in deg), and the wavelength λ (in m) as given by Panov (1971)*:

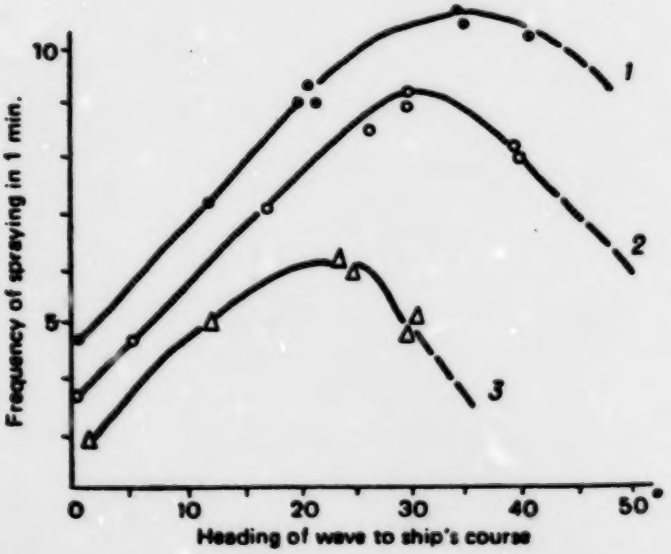
$$P_r = \frac{\lambda}{1.25\sqrt{\lambda} - V\cos\alpha} \quad \text{sec} \tag{4.2}$$

*Panov (1971) used the ship heading calculated from 0° for the ship moving into the waves and 180° for the ship moving downwind. Since in our report we use a value of 180° for the ship heading for the ship moving 'precisely' into the waves, and 0° for the ship heading with waves, we had to change a sign in the original formula of Panov (1971) from "+" to "-".



1 - wave height 1.0-1.5 m
2 - wave height 2.0-2.5 m
3 - wave height 3.0-3.5 m

Fig. 4.4. The frequency of spraying of an MFV versus the ship heading (Kultashev et al., 1972).



1 - ship speed 8.5 knots
2 - ship speed 7.0 knots
3 - ship speed 5.5 knots

Fig. 4.5. The frequency of the spraying of an MFV as a function of ship heading and ship speed (Kultashev et al., 1972).

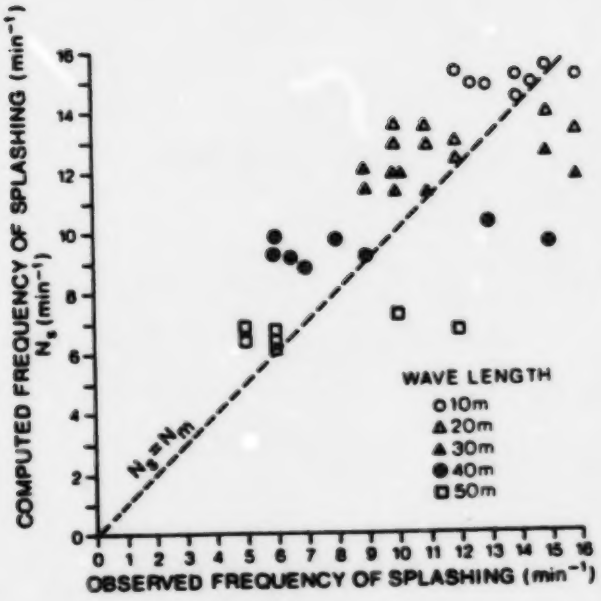


Fig. 4.6. Frequency of splashing an MFV with wave-generated spray computed by Panov's (1971) empirical formula (Eq. 4.1) vs. the observed frequency of splashing the ship with wave-generated spray abstracted from Panov (1971) (Zakrzewski, 1987).

When the wave length is unknown, one can compute P_r using the formula (Zakrzewski, 1986):

$$P_r = \frac{1.5616\ P_w^2}{1.562\ P_w - V \cos \alpha} \quad s \qquad (4.3)$$

Equation 4.3 uses the relationship between the period of the significant wave, P_w, and the wavelength, λ, given in Pierson et al. (1955). The period of the significant wave can be computed for a given wind speed if the fetch is known (Zakrzewski, 1987). The empirical formula of Panov (1971) has been tested by Zakrzewski (1986, 1987) using the data set of Panov (1971) given in Table 4.7. A comparison between the computed spraying frequencies from Eq. 4.1 and the observed frequencies of spraying, is given in Fig. 4.6. The effect of the wavelength appears to be very important. Most importantly, the formula of Panov (1971) does not underestimate the frequency of spraying of an MFV, and there is no risk that underestimation of the icing rate will occur if one used Eq. 4.1 for the estimation of the spray flux to the ship.

A very useful data set has been prepared by Golik at al. (1969) (available also in Panov, 1976) in order to correlate the frequency of the spraying of an MFV with the speed of the relative wind. This shows that the frequency of the spraying of an MFV increases with the relative wind speed (Fig. 4.7).

4.2.3. The measurement of the spray cloud parameters

Measurements of the spray cloud parameters were conducted on two Soviet ships ("Iceberg" in 1969 and "Narva" in 1973 - Table 2.1). On the research vessel "Iceberg", Mr. L.I. Gashin from AANII (the data

Table 4.7. The frequency of spraying of an MFV (in min^{-1}) as a function of the ship speed V, and the ship heading α for different wavelengths λ (Panov, 1971).

V (knots)	α (°)	λ (m)				
		10	20	30	50	100
6	180	12-13	10	9	7	5
	150	13	11	10	6-7	6
	90	14	12	10	7	6
8	180	12	10	9	6	5
	150	14	11	10	8	6
	90	14-15	12	11	9	6
10	180	12	10	9	6	5
	150	15	15	15	13	10
	90	16	16	16	15	12
12	180	12	10	9	6	5
	150	16	16	15	14	10
	90	16	16	16	15	13

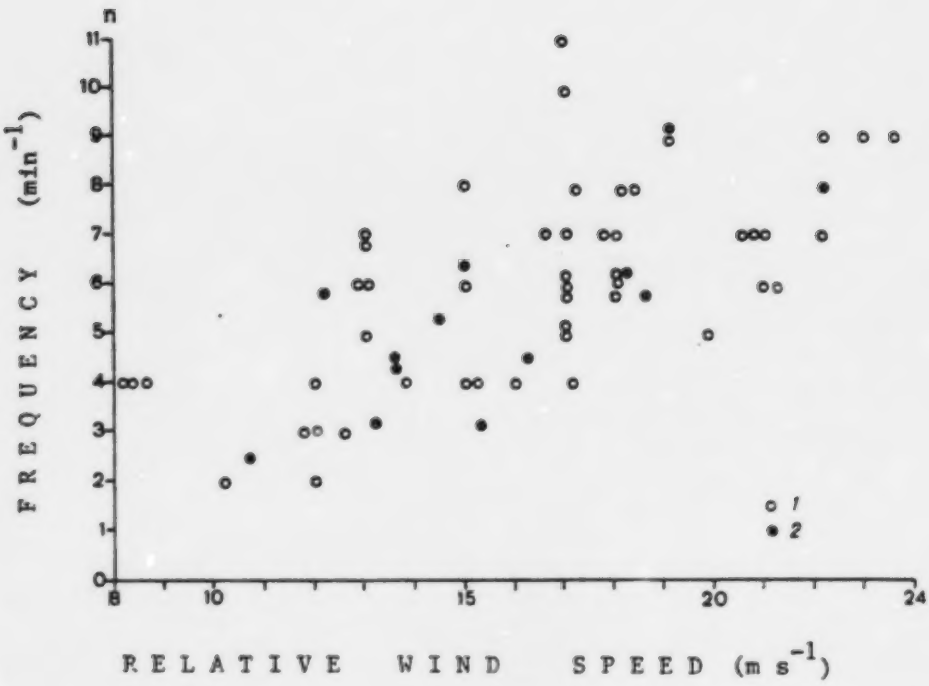


Fig. 4.7. The relationship between the frequency of spraying of an MFV and the relative wind speed (Golik et al., 1969; Panov, 1976).

1 - for actual wind speed (not in gusts)

2 - for the 'mean' wind speed over a given icing event.

set was not published by himself but written up and published later by Borisenkov (1972) and by Borisenkov and Panov (1972)) measured the droplet size spectra. The size spectrum of the droplets generated by a given ship depends on the air-sea conditions during the data collection (Panov, 1976). Moreover, the droplets in the front and rear parts of the same spray cloud have different spectra (Fig. 4.8). Gashin found a relationship between the liquid water content (in g cm^{-3}) of the spray cloud, the modal diameter of the drops, D_m, and the modal probability density, f_m, for droplets of the modal diameter (Table 4.8). To calculate the liquid water content in the spray cloud (per unit volume (1 cm^3), Borisenkov (1972) proposed the formula:

$$w = \frac{20\rho\pi_w e^2}{2^6} f_m D_m^4 \quad g\ cm^{-3} \qquad (4.4)$$

where ρ_w is the seawater density (in g cm^{-3}), f_m is the modal probability density for spray droplets of the modal diameter, D_m. According to Borisenkov (1972) the LWC varies from 0.5×10^{-4} to 2.0×10^{-4} cm^3 cm^{-3}. These somewhat odd units for the LWC used by Borisenkov (1972), mean a certain volume of fluid (water) in a unit volume of air.

Borisenkov et al. (1975) listed extremely important data on the vertical profile of the LWC, measured above the deck of the MFV "Narva" in the Japan Sea in February 1973. The measurements were conducted using several spray gauges of unknown construction, but working in such a way that the droplets were hitting an immersion oil-covered plate located inside a box of unknown size and unknown trigger mechanism. (These 'details' were deduced from scattered information given in Borisenkov et al. (1975) and in Panov (1976)). The metallic plate was covered with a film of immersion oil of thickness 5-10 mm and exposed in a direction normal to the impinging spray movement. The data were

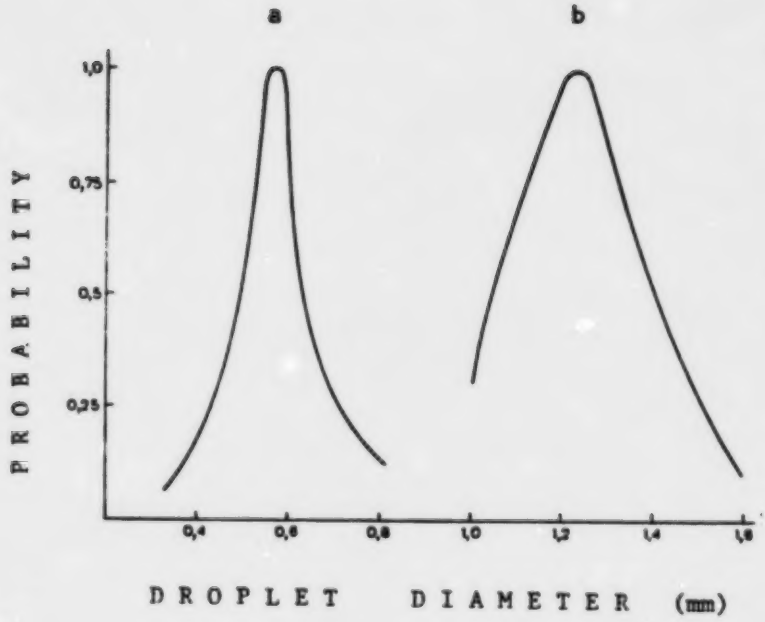


Fig. 4.8. The average droplet diameter spectrum in the front (a) and rear (b) parts of the spray cloud generated by an MFV (Panov, 1976).

Table 4.8. The relationship between the LWC (in g cm^{-3}) of the spray cloud, the modal droplet diameter, D_m, and the modal probability density, f_m, for droplets of the modal diameter (the data collected at sea by L. Gashin; published by Borisenkov, 1972).

f_m	D_m (cm)						
(cm^{-1})	0.01	0.05	0.1	0.2	0.3	0.4	0.5
0.1	$0.727 \cdot 10^{-8}$	$0.46 \cdot 10^{-5}$	$0.73 \cdot 10^{-4}$	$1.16 \cdot 10^{-3}$	$0.59 \cdot 10^{-2}$	$1.86 \cdot 10^{-2}$	$0.46 \cdot 10^{-1}$
0.2	$1.5 \cdot 10^{-8}$	$0.91 \cdot 10^{-5}$	$1.5 \cdot 10^{-4}$	$2.53 \cdot 10^{-3}$	$1.18 \cdot 10^{-2}$	$3.72 \cdot 10^{-2}$	$0.91 \cdot 10^{-1}$
0.3	$2.2 \cdot 10^{-8}$	$1.36 \cdot 10^{-5}$	$2.2 \cdot 10^{-4}$	$3.49 \cdot 10^{-3}$	$1.77 \cdot 10^{-2}$	$5.58 \cdot 10^{-2}$	0.14
0.4	$3.0 \cdot 10^{-8}$	$1.82 \cdot 10^{-5}$	$3.0 \cdot 10^{-4}$	$4.65 \cdot 10^{-3}$	$2.36 \cdot 10^{-2}$	$6.74 \cdot 10^{-2}$	0.18
0.5	$3.6 \cdot 10^{-8}$	$2.37 \cdot 10^{-5}$	$3.6 \cdot 10^{-4}$	$5.82 \cdot 10^{-3}$	$2.95 \cdot 10^{-2}$	$0.93 \cdot 10^{-1}$	0.23
0.6	$4.4 \cdot 10^{-8}$	$2.72 \cdot 10^{-5}$	$4.4 \cdot 10^{-4}$	$6.98 \cdot 10^{-3}$	$3.54 \cdot 10^{-2}$	$1.12 \cdot 10^{-1}$	0.27
0.7	$5.1 \cdot 10^{-8}$	$3.2 \cdot 10^{-5}$	$5.1 \cdot 10^{-4}$	$8.14 \cdot 10^{-3}$	$4.13 \cdot 10^{-2}$	$1.3 \cdot 10^{-1}$	0.32

analyzed using, most likely, a photographic technique that allowed one to take a photograph of the plate with the droplets entrapped in the immersion oil. The measurements were conducted at several heights above the deck up to 4.5 m.

The LWC dramatically decreases with height (Fig. 4.9). The LWC can be estimated by the formula (Borisenkov et al., 1975):

$$w(z) = 2.36 \times 10^{-5} \exp(-0.55\, z) \text{ cm}^3 \text{ cm}^{-3} \qquad (4.5)$$

where z (in m) is the height above the ship deck. Since the Soviets derived this formula using approximately fifty spray samples, this vertical profile of the LWC seems to be a valid one. However, one must be aware that under varying weather, oceanographic and ship motion conditions, the LWC will likely differ from that during the above experiment. Since the Soviets listed the basic air-sea and ship motion parameters occurring during the experiment, Zakrzewski (1987) has attempted to derive a formula for the LWC that takes into account any air-sea and ship motion parameters and the results of the Soviet measurements. The following formula has been proposed (Zakrzewski, 1987):

$$w = 6.46 \times 10^{-5} H V_r^{2} \exp(-0.55\, h) \quad \text{kg m}^{-3} \qquad (4.6)$$

where w is the LWC, H is the significant wave height (in m), V_r is the ship speed relative to the moving waves (in m s^{-1}), and h is the height above the ship deck (in m).

More valuable data were listed by Borisenkov et al. (1975), who calculated the LWC of the spray cloud for several droplet size categories (Table 4.9).

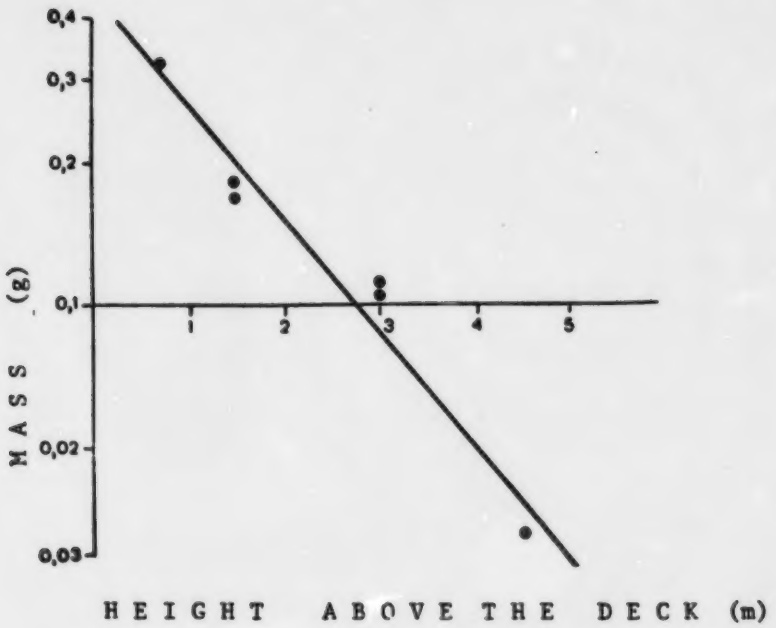


Fig. 4.9. The relationship between the average mass of spray entrapped inside the spray gauge during a single spraying event, and the height above the ship deck (Borisenkov et al., 1975).

Table 4.9. Percentage contribution to the total LWC by spray droplets of a given size category, as measured in the Sea of Japan in 1973, for central parts of the spray clouds (Borisenkov et al., 1975; Panov, 1976).

Droplet diameter (mm)	Frequency of droplet size (%)	LWC for droplets of given size category (%)	LWC $cm^3\ cm^{-3} \times 10^{-5}$
0-0.64	1	1.5	0.195
0.65-0.78	8	2.5	0.325
0.79-0.96	30	10.5	1.36
0.97-1.16	22	14.5	1.89
1.17-1.32	18	22.5	2.93
1.33-1.51	10	17.5	2.28
1.52-1.67	6	16.5	2.15
1.68-1.81	5	14.5	1.89

Based on a single set of measurements, Borisenkov et al. (1975) stated that the duration of the spray cloud residence over the MFV "Narva" was equal to 5.8 s and the measured speed of the spray cloud movement above the ship deck was equal to 6 m s^{-1}. We are confident that these data are strictly valid only for the same MFV and for the same weather, oceanographic, and ship motion conditions as those during the above field experiment on the MFV "Narva" (wind speed 8-13 m s^{-1}; ship heading 110°-90°; ship speed 5-6 knots; sea state 5-6). Some ideas about a general formula for calculating the residence of a spray cloud, Δt, over an MFV have been given by Zakrzewski (1987). This can be estimated using the significant wave height (H, in m) the ship speed relative to the moving waves (V_r, in m), and the wind speed (U_{10}, in m s^{-1}). The derived formula is:

$$\Delta t = 20.62 \frac{HV_r}{U^2} \quad s \tag{4.7}$$

The speed of spray cloud movement above the ship should be calculated by following the spray droplets, as had been proposed in the ship spraying model of Zakrzewski et al. (1987b). Only by such a technique can one model the movement of the spray cloud generated by a ship-wave collision (Fig. 4.10).

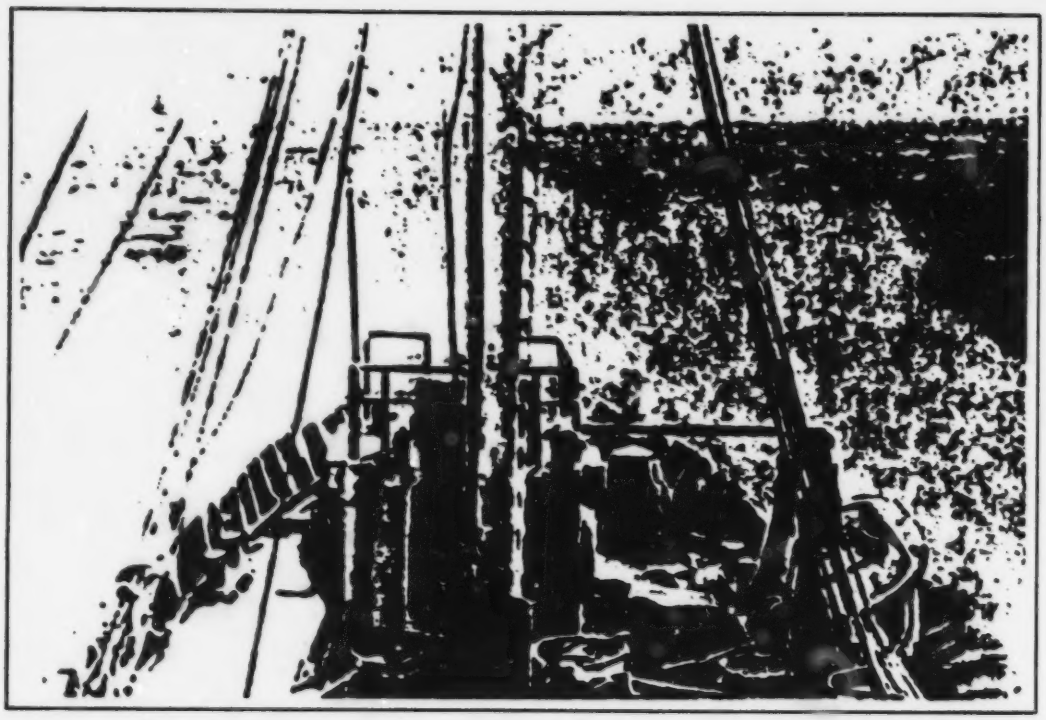


Fig. 4.10. An MFV in moderate seas (Panov, 1976).

5. THE OCCURRENCE OF ICING EVENTS ON SOVIET SHIPS

We approached the analysis of the occurrence of icing events on Soviet vessels by studying:

(a) the causes of ship icing,

(b) the distribution of ship icing events over the ocean,

(c) the weather and oceanographical conditions resulting in the icing of ships,

(d) the timing of potential ship icing and the possibility of experiencing icing during various intervals.

5.1. The Causes of Icing on Ships

The causes of icing on Soviet ships have been assessed using available publications which provide details about the results of Soviet studies of the occurrence of icing events on Soviet ships. There are only a few reports which are of value for this purpose (Kravtsov and Stadnik, unpublished manuscript; Shekhtman, 1967, 1968; Lebiediev, 1969; Kovrova et al., 1969; Vasil'yeva, 1971).

The unpublished study of Kravtsov and Stadnik has been discussed by Borisenkov and Panov (1972). Other authors (e.g., Panov, 1976) have then referred to the report of Borisenkov and Panov (1972) as if it were an original source, even though Borisenkov and Panov (1972) acknowledged several times that they were not using their own data and conclusions. Kravtsov and Stadnik analyzed more than 2000 cases of icing in the Northwest Atlantic Ocean, the Greenland, Norwegian, Barents, Baltic and Japan seas, and in the Sea of Okhotsk. These took place from 1955 to 1967 (Borisenkov and Panov, 1972). According to this

study (Table 5.1), 89.8% of all icing events were caused by sea spray. Mixed icing caused by spray and supercooled fog (or supercooled rain, or snow), and atmospheric icing are much less frequent. We found that later Aksyutin (1979) quoted the same numbers as Borisenkov and Panov, but claimed that the source materials contained 3000 documented icing events, reconstructed from icing reports which were provided by the Soviet fishing vessels. Aksyutin refers to a special Soviet publication (Guide for forecasting ship icing danger, 1972) which mentions about 3000 reports obtained from ships.

Since the frequencies of occurrence of the various causes of ship icing are precisely the same as those in the report of Kravtsov and Stadnik, it is likely that Aksyutin failed to distinguish between the total number of ship icing reports (3000) and the number of reports which had been analyzed (~2000).

Shekhtman (1967) analyzed several hundred icing events on Soviet ships from the period of 1965-1966. Sea spray appeared to be the primary cause of icing of these ships (89.0%). Other types of icing were much less important (mixing icing - 8.0% atmospheric icing - 3.0%). One year later, Shekhtman (1968) analyzed 400 cases of icing on ships, obtaining very similar results (Table 5.1). Panov (1976) mentions that during the period 1967 to 1973, approximately 3500 icing events were recorded on Soviet vessels. Unfortunately, no information is given about the causes of icing of ships. In the same report Panov quotes the results of the Kravtsov and Stadnik study (although he refers to Borisenkov and Panov (1972) rather than quoting the original source material). It is therefore very unlikely that this huge data set of

3500 icing reports had been analyzed by that time. The data set of Lebiediev (1969) contains information about the duration of the potential icing season in the North Atlantic Ocean, and in the Barents, Norwegian and Greenland seas. Unfortunately, there is no information on the causes of ship icing in these seas. The cause of ship icing is directly related to the mechanism by which water is delivered to the ship. This in turn depends very strongly on whether the ship operates in waters free of sea ice or within pack ice fields. In the latter case, the development of waves is inhibited by the sea ice and there is no spray flux to the ship. Only in marginal pack ice zones, where the waves are not reduced by the sea ice, can a ship be flooded with sea water along with the small ice chunks. This can result in very fast growth of the ice accretion on the ship (Aksyutin, 1979; Panov, 1976). The necessity for distinguishing the sea ice conditions is clearly seen when one analyzes the data of Kovrova et al (1969) from the Arctic seas (Table 5.1). Only 50% of the analyzed cases of ship icing are due to spray, whereas 41% of the icing events are the result of mixed icing, and 9% are due to atmospheric icing. Spray icing can occur in the Arctic when ships operate in open water and in ice-free areas (July-September, or July-October). Here they are exposed to spray generated by ship-wave collisions. Mixed icing, very common here, can occur when, in relatively cold air (T_a should be somewhat below 0°C), spray is delivered to the ship surface along with snow, rain or fog. It is interesting to compare the frequency of occurrence of mixed icing of ships in the Arctic seas (Kovrova et al., 1969) with the equivalent Canadian data of Brown and Roebber (1985).

Table 5.1. Causes of icing of Soviet ships compared to Canadian data.

Region/ Sea	Period	Number of icing events	Cause of icing (% frequency)								Reference
			Spray	Spray and...				Atmospheric icing			
				Fog	Rain	Frost	Snow	Fog	Rain	Snow	
All seas	1955-1967	~2000	89.8		6.4		1.1		2.7		Kravtsov and Stadnik in Borisenkov and Panov (1972)
All seas	1965-1966	~300	89.0	5.7	2.3		*		3.0		Shekhtman (1968)
All seas	1965-1967	~400	89.0		7.0				4.0		Shekhtman (1968)
Barents, Kara Laptiev, East Siberian, Chukchi seas	1967-1970	2269	50.0		41.0				9.0**		Kovrova et al. (1969)
Canadian Eastern Arctic	1973-1981	69	56.4	0.0	2.9	-	-	33.3	7.3	-	Brown & Roebber (1985, Table 4.5)
Canadian Western Arctic	1973-1982	40	60.0	7.5	0.0	-	-	22.5	10.0		Brown & Roebber (1985, Table 4.6)
Waters east of Canada	1970-1984	1041	93.1	1.3	1.5			1.2	2.8		Brown & Roebber (1985, Table 4.1)

* We think that Shekhtman (1967) analyzed only those ship icing reports that did not include spray-snow mixed icing;
** Mostly due to supercooled fog;

From Canadian Coast Guard icing questionnaires, Brown and Roebber (1985) found that snow was frequently reported during spray icing events off the east coast of Canada. The snow is a result of the thermal instability associated with the passage of cold air over open water, and is usually reported as squalls or showers. Brown (pers. comm.) indicated that there was no evidence that the snow contributed significantly to accretions formed by freezing spray. However, the likelihood of mixed snow and spray accretion is more plausible than freezing spray and freezing rain which usually occur with quite different synoptic conditions. The 41.0% frequency of spray and rain icing reported by Kovrova et al. (1969) therefore appears a little suspect.

5.2. The Geographical Distribution of Icing Events on Soviet Ships

Icing of a ship can occur whenever the water is delivered to the ship surface and the heat flux from the wetted surface is sufficiently large to result in the growth of ice. Borisenkov and Panov (1972) stated that the following factors affect ship icing: (1) the air and sea surface temperatures, (2) wind speed, wind direction, and the duration of the wind, (3) relative wind speed, (4) swell, (5) precipitation and fog, (6) the local sea depth, (7) sea ice. Besides the above factors, the intensity of ice growth on a ship and the ice load due to icing over the entire vessel depend on (Borisenkov and Panov, 1972): (1) the ship freeboard, (2) the construction of the ship bow and the ship draft, (3) rigging and masts (potential ice collectors), (4)

additional cargo (equipment) stored on the ship deck, and (5) ship manoeuvering.

Borisenkov and Panov (1972) presented two maps (Figs. 5.1 and 5.2) showing the locations of the icing events on Soviet ships. Fig. 5.1 shows the positions of the Soviet vessels during the icing events in the Norwegian and Barents seas; Fig. 5.2 shows comparable data for the North Pacific Ocean, the Sea of Okhotsk, and the Japan and Bering seas. One can easily notice that the locations of the ship positions when icing was in progress are concentrated in the main fishing zones (the Barents Sea shelf; the Bering Sea shelf near St. Paul Island; the zone alone the Kurile Islands; the western part of the Japan Sea). The other locations of the ship icing events seem also to reflect the main navigational lanes of Soviet ships. The same obvious remarks also apply to a more general map given by Panov (1976) which shows, in addition to the above seas, the cold waters of the North Atlantic Ocean and along the Great Northern Sea Route (Fig. 5.3).

In the period from 1955 to 1967 approximately 2000 icing events were reported by Soviet ships (Kravtsov and Stadnik in Borisenkov and Panov, 1972); in the period from 1965 to 1966, ~300 (Shekhtman, 1967); in the period from 1965 to 1967, ~400 (Shekhtman, 1968); and from 1967 to 1970, 2269 ship icing events were reported (Vasil'yeva, 1971). Panov (1976) reports that a total of approximately 3500 icing events on Soviet ships were reported from 1967 to 1973. These numbers suggest a very high frequency of icing events on Soviet ships (Table 5.2).

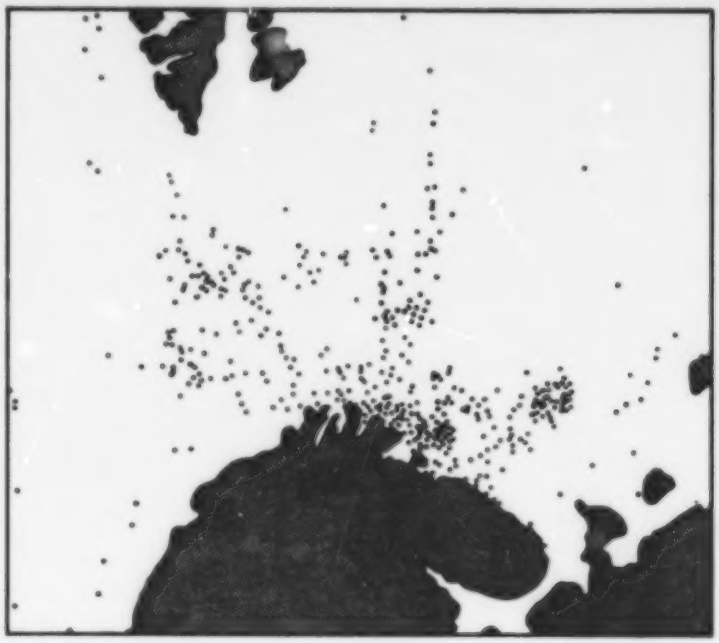


Fig. 5.1. The positions of Soviet ships during icing events in the Barents Sea and in the Norwegian Sea (Borisenkov and Panov, 1972).

Fig. 5.2. The positions of the Soviet ship during icing events in the North Pacific Ocean, and the Sea of Okhotsk and the Japan and Bering seas (Borisenkov and Panov, 1972).

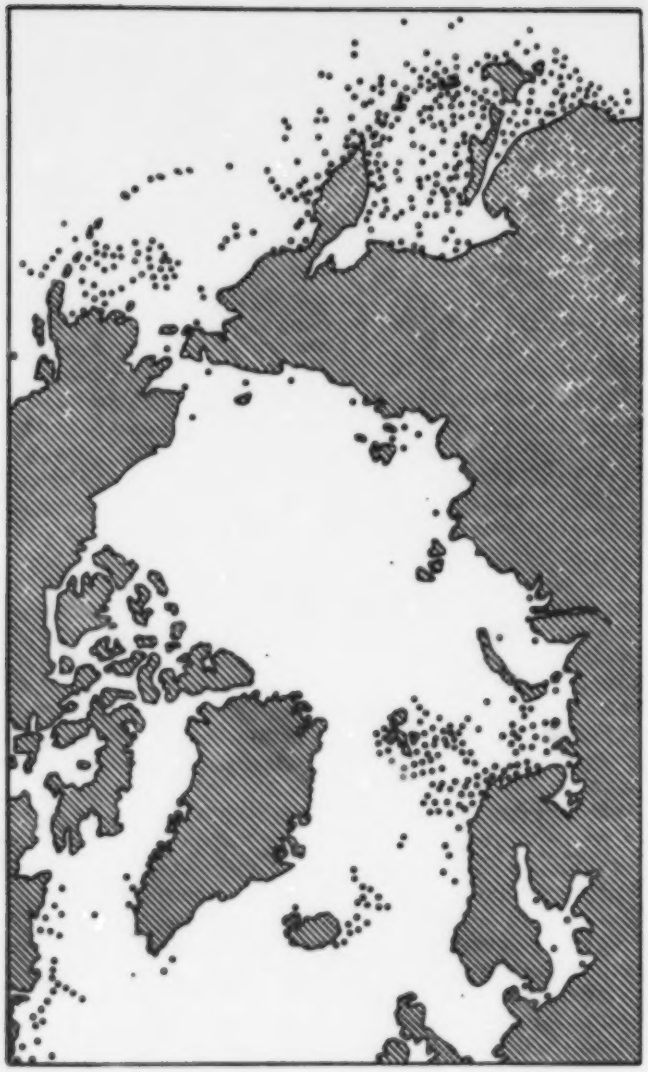


Fig. 5.3. The positions of Soviet ships experiencing icing (Panov, 1976).

Table 5.2. Mean annual numbers of icing events on Soviet vessels.

Period	Mean number of reported icing events per year	Reference
1955-1967	153	Kravtsov and Stadnik (1972)
1965-1966	150	Shekhtman (1967)
1965-1967	133	Shekhtman (1968)
1965-1973	390	Panov (1976)
1967-1970	570	Vasil'yeva (1971)

The above calculated mean annual numbers of icing events on Soviet ships show a dramatic increase beginning in 1967. Since it is unlikely that the Soviets significantly increased the number of their vessels, or scheduled many more ships for winter operations, we deduce that this increase in the number of reported icing events was apparently caused by the launching of the USSR Ministry of Fisheries data collection program. The resulting increased awareness of icing by Soviet navigators, and their concern for providing the weather offices with ship icing reports, may also have been a factor.

Borisenkov and Panov (1972) have compiled the data of Lebiediev (1969) and the data of Shekhtman (1967), and have calculated the number of reported icing events on Soviet ships in the North Atlantic and Pacific oceans, and several other seas (Table 5.3).

Similarly, Vasil'yeva (1971 analyzed 2269 ship icing events (Table 5.4) on Soviet vessels operating all over the world, and found

Table 5.3. Potential icing season and the frequency of experiencing icing by ships during the icing season (according to Kovrova et al., 1969; Lebiediev, 1969; Shekhtman, 1967; and Borisenkov and Panov, 1972).

Sea	No. of reported icing events	Potential icing season	Probability of experiencing ship icing during the icing season (%)
NW Atlantic Ocean	85	15 Dec - 15 Mar	92
Norwegian & Greenland seas	109	15 Dec - 31 Mar	77
N Atlantic Ocean	63	15 Dec - 15 Apr	92
Barents sea	390	1 Jan - 15 Mar	78
Baltic Sea	21	15 Dec - 29 Feb	85
Baffin Sea, Hudson Bay	7*	1 Dec - 31 Mar	96*
Newfoundland area	15	1 Jan - 15 Mar	79
Bering Sea	185	1 Dec - 31 Mar	70
Okhotsk Sea	337	1 Dec - 31 Mar	70
Japan Sea	226	1 Dec - 19 Feb	85
NW Pacific Ocean	183	15 Dec - 31 Mar	79
Arctic seas, (Kara Sea, Laptiev, East Siberian Sea, Chukchi Sea	71	15 Jun - 15 Nov	100

*This data is suspect because one cannot obtain the probability of 96% out of only 7 cases.

that 83% of the reported icing events had occurred in the Barents, Norwegian, and Bering seas and in the Sea of Okhotsk.

Table 5.4. The occurrence of icing on Soviet ships in the period 1967 to 1970 (Vasil'yeva, 1971).

Sea	Number of icing events on ships (5)
The Barents and Norwegian seas	877 (38.6%)
The Sea of Okhotsk	571 (25.2%)
Bering Sea	437 (19.3)
NW Pacific Ocean	182 (8.0%)
Japan Sea and Tatar Strait	140 (6.2%)
Baltic Sea	44 (1.9%)
Black Sea	18 (0.8%)
Total	2269 (100%)

5.3. Weather and Oceanographical Conditions Favourable to Icing on Ships

The USSR Ministry of Fisheries data collection program resulted in a better understanding of the weather and oceanographical conditions favourable to the icing of sea-going ships. A very large number of icing reports collected over several years on several hundred Soviet ships permitted the investigators from the Arctic and Antarctic Research Institute to determine the ranges of the air temperatures, sea surface temperatures, and wind speeds favourable to the progress of icing on ships, and to determine also the threshold values of these parameters that result in the cessation of icing.

Based on the analysis of more than 2000 documented icing events of ships, Kravtsov and Stadnik (Borisenkov and Panov, 1972) concluded that icing of ships occurred for air temperatures from 0°C to -26°C, sea surface temperatures from -1.8 to +6.0°C, and for wind speeds from 0 to 30 m s^{-1}. Panov (1976) used a data set of 3500 ship icing events, and extended the range of wind speeds recorded during the progress of icing of a ship to 55 m s^{-1}. Shekhtman (1967) reported a few cases of ship icing for which the sea surface temperatures were as high as +6-8°C. This last finding is in agreement with Mertins (1968).

The maximum wind speeds of 30 m s^{-1} (Panov, 1976) reflect extreme conditions reported by Soviet ships. However, icing can progress even in higher wind speeds, providing that a heat transfer from a wetted ship's surface is sufficiently large to result in the growth of ice. Similarly, the minimum air temperature of -26°C reflects the lowest air temperature reported during the icing event. If the air temperature

were lower, the icing, of course, would progress, too. However, such conditions have not yet been experienced by the Soviet ships.

One should note that the above ranges of the air-sea parameters refer to all types of icing on ships (spray icing, mixed and atmospheric icing). Spray icing progresses when the air temperature is lower than the freezing point of the water, and when the wind is strong enough to generate waves which can produce spray due to ship-wave collisions. The first condition indicates that the salinity of seawater takes on an important role as a factor determining the maximum air temperature that can result in icing of a ship (e.g., ~ -0.1 to -0.8°C) in the brakish waters of the Baltic Sea (salinities of 2-8°/$_{oo}$) and -1.8°C in the North Atlantic Ocean (salinities of 32-35°/$_{oo}$). The minimum wind speed sufficient to generate waves which will splash the ship depends on the ship size and ship design, and also on the ship speed and heading. Kultashev and Panov (1970) suggest that MFVs are splashed by spray if the wind speed is 5-6 m s^{-1} or more. For larger vessels, those with higher freeboards and more elevated ship bows, one can expect that spray icing will only occur if the wind speed is somewhat higher. On the other hand, the Soviet data of Kravtsov and Stadnik (Borisenkov and Panov, 1972) indicate that atmospheric icing, mostly caused by supercooled fog, occurs when the air temperature lies between 0°C and -4 to -5°C and the winds are low. This type of icing can occur during a calm, when ship movement through the still air enhances the cooling of the ship surface which is exposed to the impingement of supercooled fog droplets. Similar conclusions are given by Panov (1976) who claims that atmospheric icing due to supercooled rain (or fog) can occur in low winds and air temperatures from -2°C to -5°C. Panov (1976) also presents several figures

giving the cumulative and differential frequencies of the air temperature, sea surface temperature, wind speed and the wave height for the analyzed icing events* on Soviet ships (Fig. 5.4).

Most of the icing events of all types on Soviet ships occurred with air temperatures from -2°C to -16°C, and wind speeds from 6 to 18 m s^{-1}. Icing is equally likely to occur with any sea surface temperature from -1.5°C to +5.0°C. Rozenberg (1971a) analyzed ship icing reports from the Labrador, Barents, Norwegian, Bering and Japan seas and the Sea of Okhotsk andproduced histograms of the air temperatures (Fig. 5.5a) and wind speeds in (Beaufort) (Fig. 5.5b) measured during the icing events. This report shows that icing of ships occurs most frequently at air temperatures ranging from -5°C to -10°C. Wind forces from 4 to 8 Beaufort appear to be the most frequent. Such wind speeds appear to be quite common in the North Atlantic Ocean during the winter, because of the steep pressure gradients associated with polar lows moving from E to W (or SW to NE) over the North Atlantic Ocean towards Greenland (Fig. 5.6) or Scandinavia.

The effect of weather conditions on the degree of severity of icing was noticed by Borisenkov and Panov (1972). They recognized the following degrees of ship icing severity (Table 5.5). It is interesting that the Soviets do not use any of the well-known icing severity criteria (e.g., Mertins (1968)) that correlate the degree of severity of icing with the icing rate given in cm/24 h or some other similar system. Based on the analysis of several ship icing reports and on the results

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*Unfortunately, it is not clear whether Panov (1976) considered the data set of 2000 icing events (Kravtsov and Stadnik) or the data set of 3500 icing events (Panov, 1976).

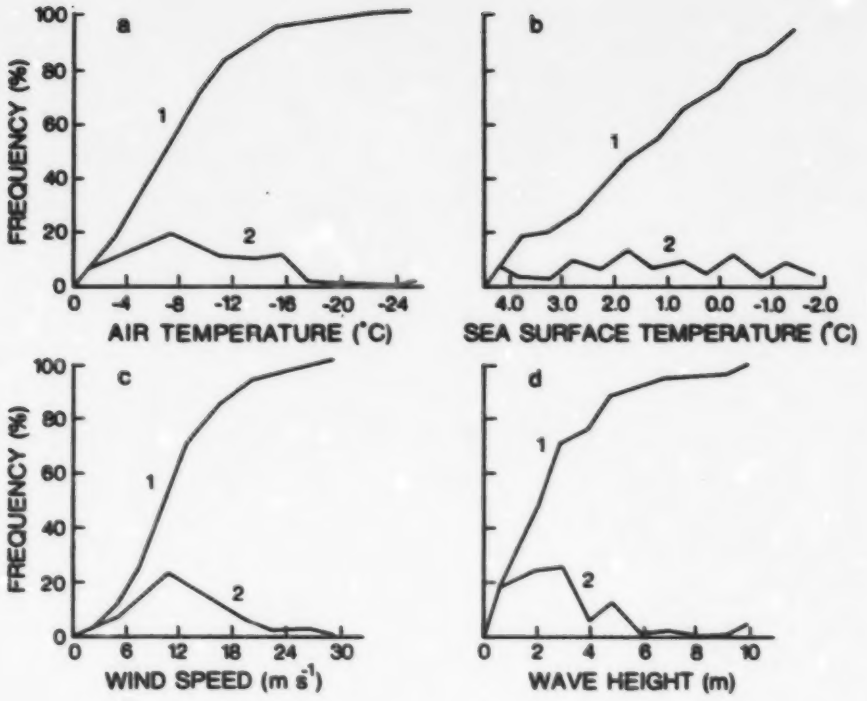


Fig. 5.4. The cumulative (1) and differential (2) frequencies of the air temperature (a), sea surface temperature (b), wind speed (c), and wave height (d) as shown by Panov (1976) for the icing events experienced by Soviet ships.

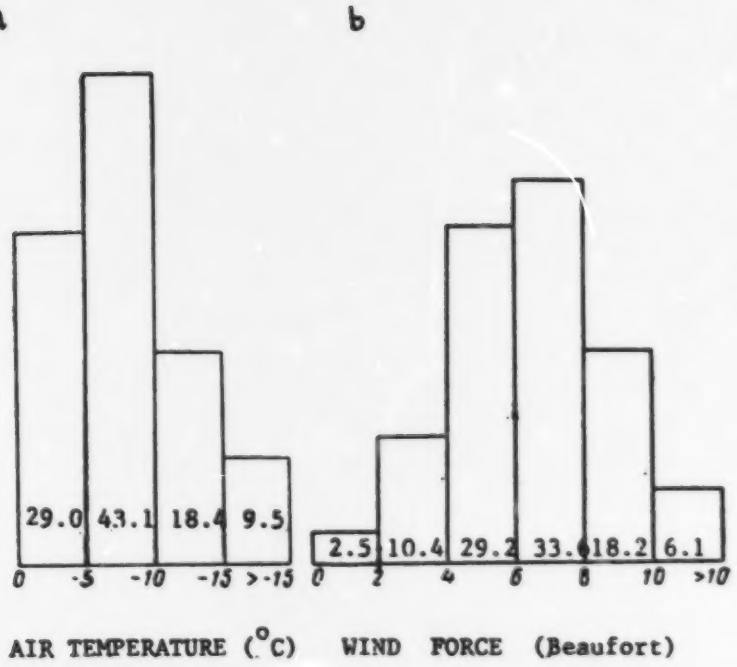


Fig. 5.5. The frequency of the air temperature (a) and the wind force (b) measured during icing events experienced by Soviet ships (from Rozenberg, 1971, according to Aksyutin, 1979).

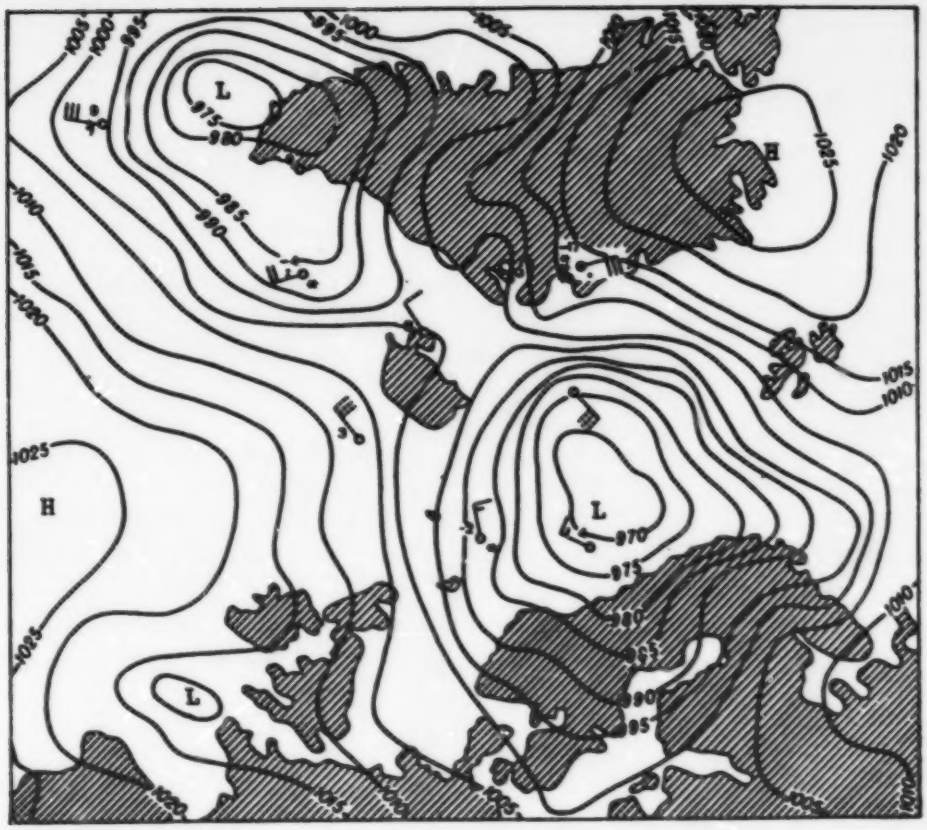


Fig. 5.6. Surface weather chart for the North Atlantic Ocean (2100Z, 28 January 1968). Pressures are in mb. (According to Panov, 1976).

of the measurements of incremental ice loads on Soviet vessels during icing events, Borisenkov and Panov (1972) attempted to determine the weather and oceanographic conditions resulting in the progress of icing of each of the above degrees of severity. They considered only the air temperatures and the wind speed (Table 5.5).

Table 5.5. The degree of icing severity as a function of the air temperature and wind speed (Borisenkov and Panov (1972)).

Degree of icing severity*		Air temperature T_a (°C)		Wind speed U_{10} ($m\ s^{-1}$)
light		$T_a \leq -3°C$	and	$U_{10} < 9\ m\ s^{-1}$
	or	$-3°C < T_a < 0°C$	and	$U_{10} \geq 0$
heavy		$-8.0°C < T_a \leq -3.0°C$	and	$9\ m\ s^{-1} \leq U_{10} < 15\ m\ s^{-1}$
very heavy		$T_a \leq -3.1°C$	and	$U_{10} \geq 15\ m\ s^{-1}$
	or	$T_a \leq -8.1°C$	and	$U_{10} \geq 9\ m\ s^{-1}$

*Icing severity: light (<1.5 tonnes/h); heavy (1.5-4.0 tonnes/h); very heavy (≥4.0 tonnes/h).

Basically, as the wind speed increases and the air temperature decreases, the icing rate is higher. The above tendencies seem to be appropriate; however, we think that one should take into account the sea surface temperature as well. Since the sea surface temperature dramatically affects the heat balance of the icing surface because of the latent heat flux with the impinging spray, the icing rate should decrease with increasing sea surface temperature, even though the wind speed and air temperature remain unchanged. For sea surface temperatures greater than 8°C, spray icing cannot progress even in very cold air. Therefore, we are confident that correlating the icing rate only with air temperature and wind speed, as done by Borisenkov and Panov (1972), seems to be too simplistic, and can result in errors in estimating the icing rate.

Kravtsov and Stadnik investigated the threshold values of the air-sea parameters involved in the growth of ice on Soviet ships of various sizes (Table 5.6). They found that, under given air-sea conditions, the icing of fishing vessels progresses at a rate which is independent of the size of the vessel. One should note, however, that all of the vessel types considered were small ships, even though a trawler with a displacement of 1000 tonnes is considered to be a large fishing vessel.

Borisenkov and Panov (1972) stated that the icing of ships in the North Atlantic Ocean and in the Greenland and Norwegian seas begins at air temperatures higher by 1-2°C and in wind speeds greater by 1-3 m s^{-1} than in the Barents Sea. There is no explanation given for the above findings, which suggest that the 'icing regimes' of these seas

Table 5.6. The basic air-sea parameters recorded during the progress of icing on ships of different displacement. The number of analyzed cases is given in parentheses. (According to Kravtsov and Stadnik in Borisenkov and Panov (1971))

Hydrometeorological conditions	Displacement (tonnes)					
	≤500		500-1000		>1000	
	light icing	heavy icing	light icing	heavy icing	light icing	heavy icing
Air temperature (°C)	<-3.0 (161)	<-6.0 (30)	<-4.0 (301)	<-4.0 (47)	<-3.0 (324)	<-5.0 (70)
Sea surface temperature (°C)	< 2.7 (135)	< 3.7 (15)	< 2.7 (252)	< 2.2 (34)	< 3.0 (364)	< 2.2 (57)
Wind speed ($m\ s^{-1}$)	> 6.0 (158)	> 7.0 (28)	> 6.0 (292)	> 6.0 (47)	> 6.0 (403)	> 7.0 (70)
Wave height (m)	> 1.0 (1.0)	> 2.5 (27)	> 0.5 (252)	> 1.5 (41)	> 0.5 (297)	> 1.0 (56)

are somewhat different. The lower threshold value of the air temperature for the onset of icing in the Barents Sea compared with the North Atlantic Ocean, and the Greenland and Norwegian seas may be the result of generally warmer sea surface temperatures. Since the warming effect of the North Atlantic current on the temperatures of the Barents Sea is easily noticeable on sea surface temperature maps (Fig. 5.7), one may presume that the waters experienced in the Barents Sea were warmer than in the other listed areas. However, during the winter the situation reverses and the sea surface temperature in the Barents Sea appears to be cooler than that in the North Atlantic Ocean (excluding the Labrador Sea, the waters east of Newfoundland, and the waters near the ice edge in the Greenland Sea). Therefore, the lower threshold value of the air temperature for icing onset in the Barents Sea seems rather to indicate that the spray flux to the ship (and the heat flux associated with it) could be higher in the Barents Sea than in other parts of the North Atlantic. Moreover, one can go further and infer that the frequency of spraying of a ship in the Barents Sea must be higher than in the other parts of the North Atlantic, because the other terms determining the equation of the spray flux to the ship should remain unchanged for given air-s parameters. The differences in the threshold wind speeds suggest tha he waves which splash a ship must be generated by higher winds in the North Atlantic and in the Greenland and Norwegian seas than in the Barents Sea. We suspect that the reported differences in threshold wind speeds permitting ship icing are caused by different fetches in the above seas and their effects on the wave steepness. It is known (Aksyutin, 1979); Panov, 1976) that a ship moving into the

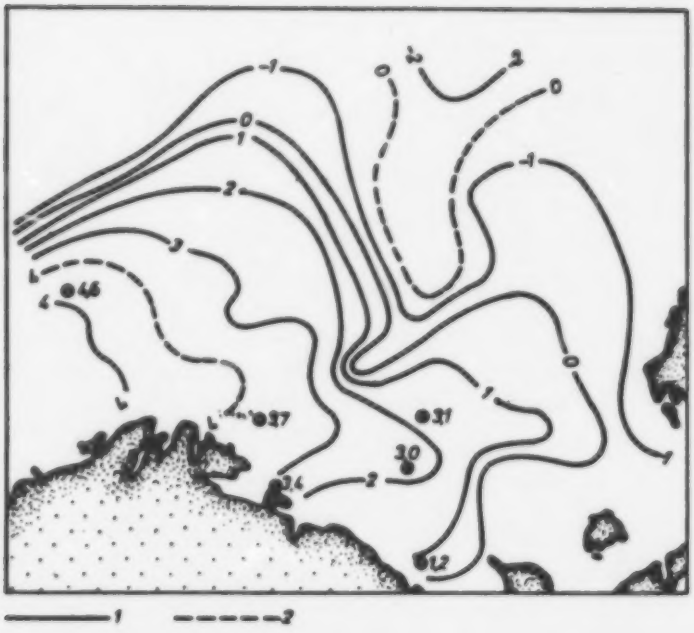


Fig. 5.7. Isotherms of the sea surface temperature in the Barents Sea during the period from 17 to 20 April 1973 (Girdyuk et al., 1977).

1 - air-borne thermal radiometer data
2 - calculated using statistical relationships between the sea-surface temperature and the air temperature, wind speed and air pressure.

waves generates spray that splashes the ship at lower wind speeds if the waves are shorter. In the entire North Atlantic Ocean area, the icing of ships most commonly occurs with NW-N-N-E winds and sufficiently low air temperatures. For these wind directions, the fetch in the Barents Sea appears to be much smaller than in the North Atlantic Ocean and the Norwegian and Greenland seas. This is especially true if the eastern and northern parts of the Barents Sea are covered by sea ice in winter. Therefore, for a given wind speed and the above wind directions, one can expect, in the Barents Sea, shorter waves than in the rest of the North Atlantic Ocean. Consequently, the ships can be sprayed in lower winds in the Barents Sea. However, the frequency of spraying is higher there and, because of this, the heat flux associated with the impinging spray is also higher. Consequently, the air temperatures required for sufficient cooling of the wetted ship surface to cause icing, should be lower in the Barents Sea than in the North Atlantic Ocean and in the Greenland and Norwegian seas.

In the conclusions of the Soviet investigations of the weather and oceanographic conditions favourable for ship icing, it is noted that the frequency of heavy and very heavy icing is especially high in the Norwegian Sea (30%). In the Japan Sea icing of such severity is almost half as frequent (17% of analyzed ship icing events (Borisenkov and Panov, 1972)).

5.4. The Period of Potential Ship Icing and the Frequency of Icing at Sea

Several hundred ship icing reports permitted Lebiediev (1969) and Shekhtman (1967) to determine the duration of the period of potential ship icing for several seas (Table 5.3). The season is three to four months long in the North Atlantic and North Pacific oceans, and the neighbouring seas. In the Arctic basin, however, the season of potential ship icing is five months long. These data show that the weather and oceanographical conditions favourable to icing of ships can be experienced by ships during 3-5 months a year depending on the area. However, the conditions favourable to ship icing do not occur continuously over the entire period of potential icing listed in Table 5.3. Several hundred ship cruises performed during the winter season permitted the Soviets to estimate the probability of experiencing icing by their vessels. The probability of icing of ships is as low as 70-80% in the Norwegian, Greenland, and Bering seas, the Sea of Okhotsk, and in the North West Pacific Ocean. It is much higher ($\geq$90%) in the North West and North Atlantic Ocean, in the Hudson's Bay, and in the Baffin Sea. The probability of experiencing icing is 100% only in the Arctic seas. This means that all vessels operating in this area have experienced icing (spray icing and/or atmospheric icing) at some time during each cruise.

6. ICE GROWTH RATES ON SOVIET SHIPS

Under the USSR Ministry of Fisheries data collection program, ice growth rates have been measured on several Soviet ships. Because the Soviet icing severity criterion was based on the incremental total ice load on the vessel in tonnes/h (e.g., Borisenkov and Panov, 1972; Aksyutin, 1979), most of the field data on icing rates were correspondingly collected in tonnes/h. In some Soviet reports one can find the icing rates given in g cm^{-2} h^{-1} (e.g., Panov, 1976) and, very rarely, in cm h^{-1} (Aksyutin, 1979, p. 57; Kachurin et al., 1974). The Soviets knew (e.g., Panov, 1976; Pal'tchinskii, 1967; Rybnikov, 1975) that the icing rate is not homogeneous over the ship, but that it varies over different ship components (e.g., bulwarks, decks, superstructure, etc.) even when the ship is maintaining constant speed and heading. Moreover, the icing rate appears to vary widely even over a given ship component. The latter proves that one cannot use a 'generic icing rate' (given in cm h^{-1} or kg m^{-2} h^{-1} or g cm^{-2} h^{-1}) for the entire ship. We believe that the Soviets were well aware of the variability of the ice growth rate over the ship and that this is why they decided to employ ice growth rates expressed in tonnes per hour over the entire ship.

There is very little information about the techniques used by the Soviets to measure the icing rates on their ships. Fortunately, Rybnikov (1975) described the data collected on the MFV "Piarnu" in the Baltic Sea during February 1969. He gave some details about the measurement techniques for the icing rates. Basically, the icing rates (in cm h^{-1}) were measured at several locations using metallic bars fixed to the various ship components. The bars were oriented perpendicularly

to the object's surface. The thickness of the accretion was determined (most likely every hour) by measuring the free length of the bar as it decreased due to ice formation on the ship component. Since the initial length of the bar was known, the thickness of the accretion, h_i, was most likely calculated using the simple formula:

$$h_i = L_o - L_i \tag{6.1}$$

where L_o is the initial length of the bar protruding from the ship component, Li is the measured length of the part of the bar that protrudes from the accretion after i hours of icing, and h_i is the thickness of the accretion after i hours.

We have found that the Soviets were using the measured accretion thicknesses most often to determine the ice load on the given ship part rather than to calculate the ice growth rate on the object. Only in a few cases (e.g., Panov, 1976) were the ice growth rates calculated as the mean incremental thickness of the accretion over a given period of time (e.g., 1 hour). Sometimes a mean icing rate, $\Delta\overline{h}$, has apparently been calculated for the entire icing event using, as we suspect, the simple formula:

$$\Delta\overline{h} = h_{max} / k \tag{6.2}$$

where h_{max} is the maximum thickness of the accretion on a given ship component measured during the icing event, and k is the duration of the event. For example, Eq. (6.2) was used to calculate the icing rate on the cargo vessel "Tuloma" for which the basic air-sea and ship motion parameters have been listed by Buyanov (1968). Instead of measuring the icing rates for the ship, the Soviets were much more

interested in the determination of ice loads on various ship components and on the entire vessel. For the flat components such as the sides of the bulwarks, the sides of the ship superstructure, the hatch covers, and the decks, the Soviets used the formula below as one can deduce from Rybnikov's (1975) report:

$$m_i = S\rho h_i \tag{6.3}$$

where m_i is the ice load on a given ship component after the ith hour of the icing event, S is the surface area of that component, h_i is the thickness of the accretion after the ith hour, and ρ is the density of the accretion (in kg m^{-3}). As far as we can deduce from the Soviet papers (e.g., Panov, 1976; Rybnikov, 1975), the density of the accretion was measured on the ship using a balance to weigh samples of known measured volume. Nevertheless, the density of the accretion has been assumed to be constant over the ship and over the icing event. For objects of complicated shape (e.g., deck equipment, rigging) formulae similar to Eq. (6.3) were apparently used, but we were not able to obtain any details about these.

The total ice load on the entire vessel was calculated by totalling the ice loads on all ship components. The formula used for totalling the ice load over the ship is:

$$M_i = \sum_{j=1}^{h} m_{i,j} \quad \text{kg} \tag{6.4}$$

where M_i is the total ice load on the entire vessel (in kg (or tonnes)) at the end of the ith hour of the icing event, and $m_{i,j}$ is the ice load on the jth object at the end of the ith hour of the icing event.

NOTE: **See pocket on inside back cover for TABLE 6.1**

Rybnikov (1975) reported that estimating the ice load on the ship proceeded smoothly when conditions were not very heavy. However, during the icing event of February 1969, the MFV "Piarnu" experienced such heavy conditions that the above technique for the estimation of the ice load on the entire vessel could not be implemented because of difficulties in measuring the thickness of the accretion at several locations over the ship. In order tc measure the ice load on the entire vessel, the MFV "Piarnu" was directed to the port of Tallin where immediately after arrival, the draft and the list of the ship were measured, and the lower ship side was winched up using a port crane to eliminate the ship list. No details are given about this technique, but we think that the lift force applied by the crane was measured and then used to obtain from the ship stability curves the ice load which gave rise to the list.

A careful review of the Soviet literature permitted us to extract more than one hundred thoroughly and carefully documented cases of icing of Soviet ships (Table 6.1). Most of these measurements were carried out under the USSR Ministry of Fisheries data collection program. In most cases, the icing rates are given in tonnes per hour, and they refer to the entire vessel. In Canada, icing rates on ships are commonly given in cm h^{-1} (e.g., Stallabrass, 1980; MacDonald and Jessup, 1985). In order to compare the ice growth rates on the Soviet vessels with the icing rates observed on Canadian ships, one must convert the icing rates on the Soviet ships to cm h^{-1}. The conversion in question has already been tested by Kachurin et al. (1974), who correlated the icing rates (in cm h^{-1}) on a metallic cylinder of 0.5 m diameter, predicted by their ship icing model, with the overall icing rates (in tonnes per

hour) on an MFV. Kachurin et al. used more than 50 documented icing events on Soviet ships and claimed extremely good fit (correlation coefficient 0.96). The ship spraying/icing model of Zakrzewski and Lozowski (1987), calibrated for an MFV of Soviet type, makes it possible to calculate the incremental thickness of spongy accretion on the ship's superstructure for a given ship speed and heading, wind speed, fetch, sea surface temperature, and air temperature and seawater salinity. This model can predict the ice load on the ship superstructure. Zakrzewski (1986) reviewed the data of Panov (1976) on ice loads on MFVs and acknowledged a simple correlation between the ice load on the ship superstructure and the ice load on the entire vessel. This correlation makes it possible to use the ship icing model of Zakrzewski and Lozowski (1987) applicable to calculate the total icing rate on an MFV (in tonnes per hour) for cases when the ship superstructure is splashed with collision-generated spray.

However, one must be aware that there are several differences in ship construction between Soviet and Canadian fishing vessels. In addition, it should be noted that the data set of Stallabrass (1980) was produced using the arithmetical mean of the ice growth rate on eight different ship components, and that these icing rates were based on the visually observed (not measured) maximum thicknesses of the accretion, divided by the duration of the icing event. The Soviet data are much more consistent and were obtained by much more careful measurements. Also, if the Soviets specify an icing rate in cm h^{-1}, they refer it to the appropriate ship component on which the accretion was formed. The above differences in the data sets may lead to erroneous conclusions concerning the conditions of ice growth on Soviet ships vis-a-vis the

conditions resulting in the icing of Canadian vessels. Since the work on the present project is limited to extracting the available data on ice-related parameters from the Soviet literature, we are not attempting to transform the icing rates measured on Soviet ships from tonnes per hour into cm per hour. However, we are hopeful that in the future this work might be performed for AES under a separate research contract.

Because this report is devoted to presenting the results of Soviet measurements of icing-related parameters, we do not plan to discuss any of the Soviet ship icing models (e.g., Kachurin et al., 1974; Borisenkov, 1969). However, since our report presents the Soviet field data, we decided to include two Soviet approaches to estimating the total ice growth rate on an MFV, which are exclusively based on the field data.

The first approach was developed independently* by Sharapov (1971a) and Tyurin (1970). It is based on the finding that the icing rate on an MFV can be estimated using a parameter N, which is equal to the relative wind speed (in Beaufort) multiplied by the absolute value of the sum of the sea surface temperature and air temperature:

$$N = V_B|T_a + T_w| \tag{6.5}$$

where V_B is the relative wind speed (in Beaufort), T_a is the air temperature (in °C), and T_w is the sea surface temperature (in °C). The relationship between the above parameter and the total icing rate on an MFV (in tonnes per hour) appears to be quite realistic, as one

*Although Tyurin published his paper in 1970, Panov (1976) stated that the work of Sharapov (1971a) had been completed first.

can see in Fig. 6.1. Apparently, the above relationship reflects the well-known dependence of icing rate on (1) the wind speed, (1) the air temperature, and (3) the sea surface temperature, as can be seen from the nomogram of Mertins (1968) which was produced using field data, too.

If the field data collected on MFVs in the winter of 1967/68 and 1968/69 can be extrapolated to all conditions, one can, in a very simple way, estimate the total icing rate for the entire MFV. The simplicity of this approach permitted Soviet fishermen to use Eq. 6.6 for practical purposes. Moreover, the official "Guide for forecasting of ship icing danger" (1972) contains precisely this formula for fast estimation of the icing rate on an MFV. This recommendation seems to be very reasonable. Moreover, Sharapov (1971a) suggests that the effect of snow on the icing rate may be taken into account by increasing the predicted icing rate by 10-20% (depending on the visibility, which is considered as a factor for determining the intensity of the snowfall). However, this ad hoc adjustment of Eq. 6.6 is not based on careful studies of ice growth due to the freezing of water delivered by the combined mechanism of spraying and snow impact onto a ship's surface.

The second Soviet approach (Buyanov, 1971c) to determining the icing rate on an MFV is to use a relationship between the frequency of spraying of the ship, the extent of the spraying zone over the ship, and the volume of ice formed on the ship over a given hour of the icing event. This approach is simple, but questionable. Buyanov (1971), whose sailing experience is beyond reproach, produced a special nomogram (Fig. 6.2) which, according to him, provides a navigator with reasonably correct predictions of the icing rate on an MFV (in $m^3\ h^{-1}$). We agree

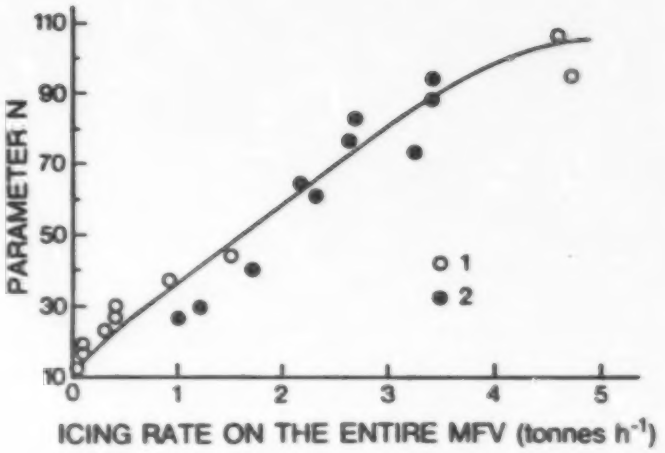


Fig. 6.1. The relationship between the parameter N (see Eq. 6.6) called by Sharapov (1971a), "the degree of severity of the weather" and the total icing rate on the entire MFV for the field data collected in 1968 (1) and 1969 (2). There is no information on the ships or the area where the measurements were carried out.

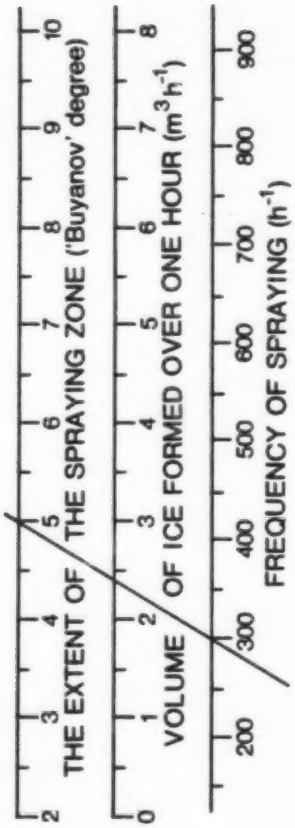

THE EXTENT OF THE SPRAYING ZONE ('Buyanov' degree)
2 3 4 5 6 7 8 9 10
VOLUME OF ICE FORMED OVER ONE HOUR ($m^3 h^{-1}$)
0 1 2 3 4 5 6 7 8
FREQUENCY OF SPRAYING (h^{-1})
200 300 400 500 600 700 800 900

Fig. 6.2. The nomogram of Buyanov (1971c) is intended to allow estimation of the incremental volume of ice over one hour of the icing event (in $m^3 h^{-1}$) on the entire MFV, by connecting with a line, the scale for the spraying of the ship (given in "Buyanov" degrees) and the scale for the frequency of spraying of the ship (per hour), through the observed extent of the spraying zone over the ship (see Table 4.2).

that the total icing rate on the entire vessel should be proportional to the total surface area of all wetted ship surfaces and that it should be dependent on the frequency of spraying of the vessel. However, the Buyanov (1971c) nomogram apparently neglects the effects of sea surface temperature and air temperature on the icing rate. These two parameters are known to govern the process of ice growth on the ship surface, and by neglecting them, Buyanov has restricted use of his nomogram to predicting icing rates only under the particular air-sea and navigational conditions for which it was derived. He claims that the nomogram reflects "the relationship between the icing rate and the spraying of an MFV" as it was observed on several MFVs operating in the Sea of Japan in 1968 and 1969. Consequently, such a nomogram can presumably be used to estimate the icing rate on ships experiencing similar weather and oceanographic conditions (and moving with the same speeds and headings) as those ships on which the original data were collected. Unfortunately, Buyanov (1971c) does not mention these conditions at all. Consequently, Buyanov's nomogram should not be used at all.

7. ICE LOADS DUE TO ICING ON SOVIET SHIPS

Ships experiencing icing at sea accumulate spongy ice on all wet ship surfaces. Ice loads due to icing reduce ship stability and, after reaching a certain critical value, cause the ship to capsize. The Soviets knew that several of their MFVs had been lost due to icing. Consequently, investigations of ship stability under icing conditions were carefully carried out on several Soviet ships under the USSR Ministry of Fishing data collection program. The measurements were conducted with the purpose of determining the magnitudes of the ice loads on ships and their effect on ship stability. In addition, the Soviets decided to critically evaluate the existing ship stability criteria for ice loads due to icing. Although many MFVs had capsized due to icing and their stability questioned (e.g., Kultashev and Panov, 1970), the Soviets surprisingly concluded that MFVs can accumulate much more ice than is permitted by the ship stability criteria of the Regulations of the USSR Registry of Shipping (e.g., Gurvitch, 1972; Dreko, 1976). In other words, the criteria for ship stability were too stringent when compared with the maximum ice loads which were still 'safe' for MFVs. Since MFVs built in the 1950s and 1960s fulfilled the standard icing stability criteria, but were nevertheless very prone to icing and to capsizing, suggesting more liberal ship stability criteria (Dreko, 1976), seems to be rediculous. Because the MFVs already have a bad record of instability in icing storms, encouraging naval architects to design ships according to more liberal requirements for ship stability under icing, appears to be ill-fated. Vessels which avoided

capsizing were not saved by the ship stability, but rather by the heroic effort of ship crews removing ice during the entire icing event (sometimes over 50 hours! (Aksyutin, 1979; Tsoy, 1968).

A further consideration is that the ship stability criteria are based exclusively on static stability curves. In heavy seas, wave impact forces and additional loads due to water flooding the ship deck can contribute to the ice load and cause capsizing even though the ice load alone may have been smaller than the critical value.

We approached the analysis of the Soviet data on ice loads due to icing by investigating:

(a) unit ice loads (in kg m^{-2}) on various ship components,

(b) total ice loads (in kg) on various ship parts,

(c) total ice loads on the entire vessel (in kg or tonnes).

7.1. Unit Ice Loads on Ship Components

The rules of the USSR Registry of shipping allow a ship to accumulate up to 30 kg of ice per square meter on horizontally oriented surfaces and 15 kg of ice per square meter on vertically oriented surfaces. Detailed measurements of ice loads were conducted on the MFV "Professor Somov" in the Barents Sea in the winter of 1969 and on the RV "Polyarnik" in the Barents and Norwegian seas in the spring of 1968 (Aksyutin, 1979). Similar measurements were conducted on the MFV "Academic Ber" in the Japan Sea in 1968 and 1969 (Kultashev and Panov, 1970). The results of these measurements are given in Table 7.1. The measured unit loads (in kg m^{-2}) appear to exceed the norms of the USSR Registry of Shipping. The above ships which experienced heavy icing did not capsize, even though the ice loads were much higher than

Table 7.1. Unit ice loads on Soviet MFVs (Aksyutin, 1979; Kultashev and Panov, 1970).

Ship	Horizontally oriented surfaces		Vertically oriented surfaces	
	Ship part	Ice load (kg m^{-2})	Ship part	Ice load (kg m^{-2})
"Academic Ber"	not specified	25.0-57.4	not specified	15.9-47.5
"Professor Somov"	upper deck	34	foremast	34
	hatches	50	bulwarks	36
	gunwale	84	front face of superstructure	7
			rigging	23
			winches	50
"Polyarnik"	main deck	35	winches	50
	gunwale	85	bulwarks	35
	hatches	50	front face of superstructure	7
			sides of superstructure	2
			deck equipment	80
			rigging of foremast	23
			storm scuppers	10

those allowed by the regulations. However, losses of other MFVs point out that ships of this type do lose stability under icing conditions. This means that the static ship stability criteria are not especially useful in determining the risk of ships capsizing under conditions of spray icing. A ship at sea is affected by several other external forces (e.g., wave impact forces, loads due to flooding of the deck, wind drag on the sail area which contributes to the diminution of ship stability, and, consequently, to ship capsizing. Under these conditions, the ship can capsize, even though for the ice loads alone, the static ship stability curves would indicate sufficient metacentric height. We believe that the dynamic ship stability criteria could be more appropriate for more accurate determination of the icing conditions under which the ship loses stability and capsizes. However, the simplest way of preventing ships from capsizing is by changing the ship design, eliminating several excess ice collectors on the ship (see Fig. 2.3). Only in this way can one expect the ice build-up to not reduce the ship stability enough to result in capsizing.

7.2. Total Ice Loads on Ship Components and their Contribution to the Total Ice Load on the Entire Ship

The detailed measurement of the thickness of the accretion formed on various ship components, along with the measurements of density of the accretion permitted the Soviet investigators to determine the total ice loads on those components. This technique for the determination of ice loads has been used for both MFVs (details in Rybnikov (1975) and MFTs (Drevitch, 1975)).

The results of the Soviet investigations of ice loads on MFVs are summarized in Figs. 7.1 and 7.2. First, the Soviets attempted to determine the frequency of icing on the various ship components. Based on a limited number of observations conducted in the Barents Sea (Kultashev et al., 1972), it was found that typically the contributions of the loads on various components to the total ice load on the entire MFV are:

(a) horizontal surfaces 30-70%

(b) vertical surfaces 15-30%

(c) deck equipment and winches 5-30%

(d) cylindrical objects (foremast, rigging) 0-30%

According to Kultashev et al. (1972, p. 130), Fig. 7.1 presents "histograms of the frequencies of icing" on the above listed groups of ship components. After careful analysis of this figure, we cannot agree with this description of Fig. 7.1. Apparently, Kultashev et al. (1972) were considering the frequency of a given percentage contribution to the total ice loads of the load on specific components, rather than "the frequencies of icing of these ship components." This anomalous nomenclature is repeated several times in this reference. However, in the most comprehensive compilation of the Soviet research on ship icing, Panov (1976) discusses this histogram of Kultashev et al. (1972) using a correct nomenclature.

Fig. 7.2 presents the contribution (in %) of the ice loads on various ship components to the total ice load on the entire vessel. One should notice that the contribution of the ice loads on the ship deck, mast and rigging, and on the deck equipment and winches to the

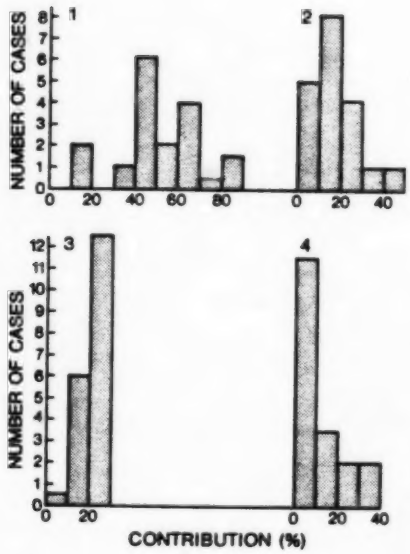


Fig. 7.1. Histograms of the contribution to the total vessel ice load of the loads on particular components. (1) horizontal surfaces, (2) vertical surfaces, (3) deck equipment and winches, and (4) mast and rigging. The mean values of the percentage contributions are 51%, 22%, 17%, and 14%, respectively, and the corresponding standard deviations are 20%, 5%, 10%, and 14% (Kultashev et al., 1972; also in Panov, 1976).

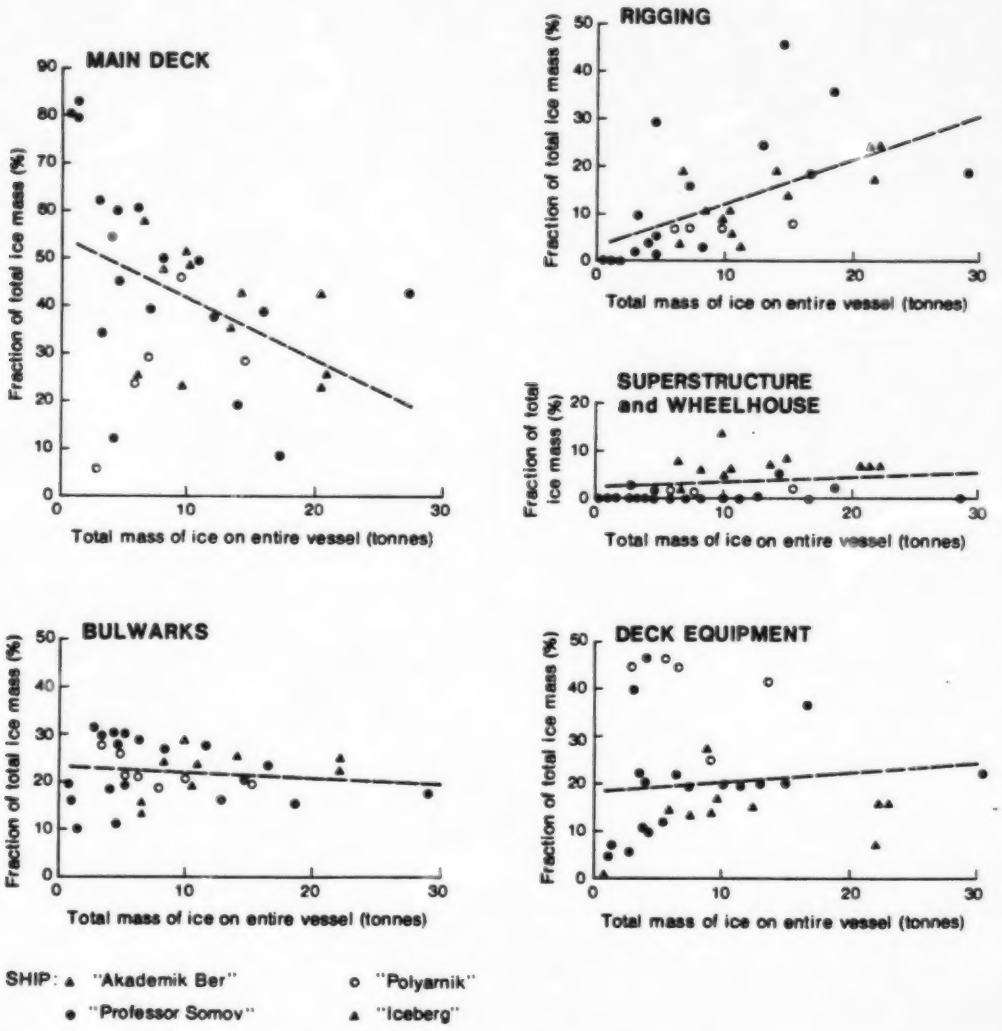


Fig. 7.2. The contribution of the ice loads on various ship components to the total ice load on the entire MFV (Kultashev et al., 1972).

total ice load on the entire MFV appears to depend on the total ice load.

This is presumably valid, not only at the end of an icing event when there is the maximum ice load on the vessel, but also at any moment of the icing event. For example, the contribution of ice loads on the mast and rigging to the total ice load on the vessel seems to increase as the total ice load increases (that is, as icing progresses). However, the ratios for vertical surfaces appear to be relatively constant, independent of the total ice load. The scatter for the vertical surfaces is also much smaller than for other ship surfaces. Zakrzewski (1986) noticed this, and by assuming that there is no time dependence for the ratio between the ice loads on the ship bulwarks and sides of the ship superstructure and the total ice load on the entire vessel, attempted to determine the ice load on the entire MFV using only the ice loads on the vertically oriented ship surfaces. However, one should be aware that in low seas, when the ship superstructure is not splashed by spray, this approach may not be used, since there is then no ice on the ship superstructure.

The measurements permitted the Soviets to calculate the mean percentage contribution of the ice load on various ship components to the total ice load on the entire MFV. For example, Aksyutin (1979) quotes the data from the MFV "Academic Ber" (Table 7.2). The ranges of the above ratio for various ship components measured on three Soviet MFVs during icing events of varying severities are given in Table 7.3.

Table 7.2. The mean contribution (in %) of ice loads on the main ship components to the total ice load on the MFV "Academic Ber" (Aksyutin, 1979).

Ship part	%
main deck	27
bulwarks	25
gunwale	24
deck equipment	17
superstructure	7

Table 7.3. Distribution (in %) of ice loads on several ship components of MFVs (compiled by Aksyutin, 1979).

Ship components	SHIP		
	"Professor Somov" (total ice load from 11.0 to 28.4 tonnes)	"Polyarnik" (total ice load from 3 to 15 tonnes)	"Iceberg" (total ice load equal to 9.8 tonnes)
main deck, gunwale, lifeboat, deck, hatches	11.5 - 49.6	21.9 - 53.7	43.8
bulwarks, winches, superstructure, wheelhouse, ship sides	14.8 - 28.4	27.8 - 28.4	21.1
deck equipment	15.6 - 32.6	11.5 - 31.3	26.9
mast, rigging	3.3 - 35.5	6.9 - 18.4	8.2

Similar measurements have been conducted for medium-sized freezing trawlers, which are larger than MFVs (overall length ~54 m; displacement 900-1000 tonnes).

The results of the investigations performed on the MFT "8434" during the period from 1968 to 1972 in the North Pacific Ocean, the Gulf of Alaska, and in the Bering Sea were published by Dervitch (1975). He analyzed the data from sixteen icing events on this trawler and found that the total ice load ranged from 12.4 to 51.0 tonnes. Based on measurements carefully carried out at 28 stations over the ship, Dervitch (1975) deduced that the contribution of the ice load on various ship components to the total ice load on the entire vessel exhibits a much smaller variation than for MFVs (Table 7.4).

Table 7.4. Distribution (in %) of ice load over the MFT "8434" (Dervitch, 1975).

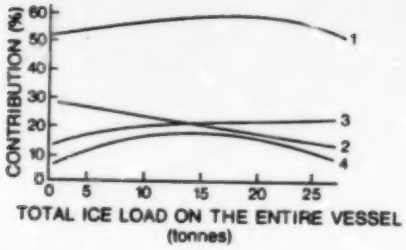
Ship component	Ratio (in %) of the ice load on the target component to the total ice load on the entire vessel
main deck, foredeck, deck equipment	51.1 - 63.5
ship sides and bulwarks	20.7 - 30.3
superstructure, wheelhouse, lifeboat deck, lifeboats	11.1 - 17.6
masts, stays, rigging	1.8 - 7.1

Based on the available data, Dervitch (1975) attempted to examine the dependence of the ice loads on the basic ship components on the total ice load on the entire MFT (Fig. 7.3). Based on Fig. 7.3 the contribution of the ice load on the ship superstructure slightly increases as icing progresses, whereas the contribution of the ice load on the ship sides and bulwarks appears to decrease. The contributions of the ice loads on the mast, rigging, and on the main deck, foredeck and forepeak appear to increase slightly until the total ice load reaches 15-20 tonnes, and then to decrease gradually . Kultashev et al. (1972) presented the results of measurements conducted on three MFTs (Fig. 7.4). The contributions of the ice loads on (1) the ship deck, (2) the bulwarks, and (3) the ship superstructure and wheelhouse to the total ice load on the entire MFV appear to be the most important.

7.3. Total Ice Loads on Soviet Ships

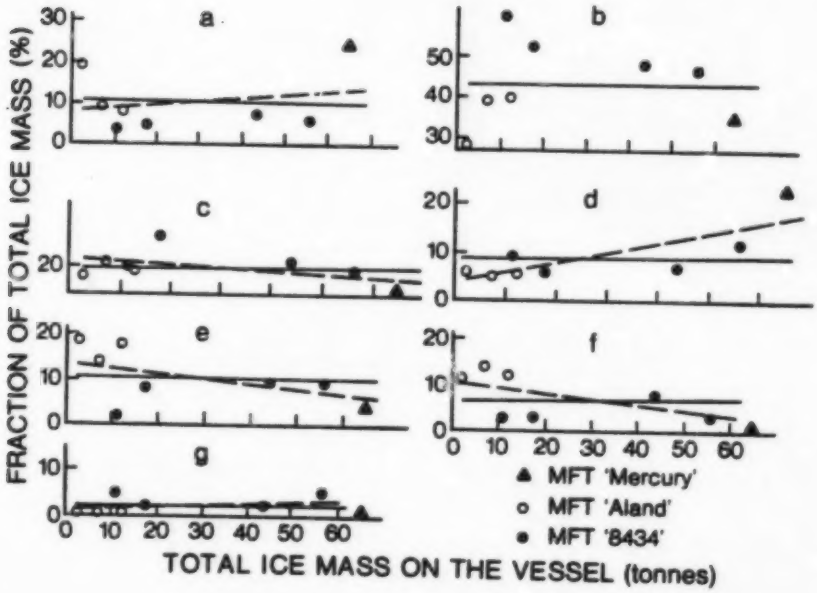
The total ice loads on Soviet ships have been investigated both for MFVs and MFTs. The most detailed list of the ice loads is given in Gurvitch (1972). Also, Panov (1976) and Aksyutin (1979) give some information.

Basically, the total ice load on a vessel depends on the intensity of icing and the duration of the icing event. Medium-sized fishing vessels have been known to survive the accumulation of 40-54 tonnes of ice (e.g., the "Piarnu" accumulated 54 tonnes of ice during her research cruise in February 1969 (Rybrikov, 1975)). However, the MFV "Boksitogorsk" lost stability when, according to estimates made by Tsoy (1968) and Netchaev (1967), 40 tonnes of ice built-up on the vessel. This difference suggests that the sea state affects ship



1. main deck, foredeck and forepeak;
2. ship sides and bulwarks;
3. ship superstructure, wheelhouse, lifeboat deck, and lifeboats;
4. masts and rigging

Fig. 7.3. Variation of the ratio between the ice load on various basic ship components and the total ice load on the entire MFT as a function of the total ice load on the MFT (Gurvitch, 1975).



1. MFT "Mercury"
2. MFT "Aland"
3. MFT "8434"

Fig. 7.4. The ratio between the ice load on (a) foredeck and forepeak, (b) main deck and deck equipment, (c) gunwale and bulwarks, (d) mast and rigging, (e) superstructure and wheelhouse, (f) ship sides, and (g) the boat deck to the total ice load on the MFT (Kultashev et al., 1972).

stability very strongly.

The "Piarnu" upon accumulation of 54 tonnes of ice was operating in the Baltic Sea and in the Gulf of Finland where the waves were much reduced due to the small fetch and shallow sea, whereas the "Boksitogorsk" was lost in the Bering Sea and was exposed to waves 6-7 m high (Aksyutin, 1979; Tsoy, 1968).

The ice load of 54 tonnes on the MFV "Piarnu", as reported by Gurvitch (1972) is apparently the largest ever reported from an MFV which returned from cold seas. The second largest ice load was reported (Gurvitch, 1972) on the MFV "Kiedrovyi" on 5 February 1968 operating in the Bering Sea (38 tonnes).

Aksyutin (1979) has given an exhaustive description of the icing event on the MFV "Ataman'" in the Bering Sea on January 18-19, 1965, during the very icing storm in which four other Soviet MFVs and six Japanese ships were lost. The "Ataman'" experienced very heavy icing (maximum icing rate of 15-20 tonnes per hour!) during a period of 50 hours. The total ice load on the vessel fortunately never exceeded the critical value because the desperate crew continually removed the ice, working non-stop over 50 hours. Ice removal apparently saved the ship, even though approximately 50 tonnes of ice accumulated on the vessel and it experienced a list of 48° (half of the ship deck was beneath the water!).

MFTs are larger than MFVs, and can therefore survive heavier ice loads. Drevitch (1975) quotes 51 tonnes of ice on the MFT "8434", and the data of Kultashev et al. (1972) suggest that on the MFT "Mercury", during one icing event, the total ice load was approximately

66 tonnes (Fig. 7.4). Gurvitch (1972) states that this icing event occurred in Skagerrak from 30 January to 1 February 1967 (Table 6.1) and gives a value of the ice load of 64.9 tonnes.

8. SOVIET INVESTIGATIONS OF THE PHYSICAL PROPERTIES OF ICE ACCRETION ON THEIR SHIPS

Besides the data on the spraying of ships and on icing rates and ice loads on ships, the USSR Ministry of Fisheries data collection program included an investigation of the physical and chemical properties of the accretions. The Soviets focussed on two properties of the accretion: (1) the adhesive strength of the accretion, and (2) the density of the accretion.

The data on the above properties of the accretion were badly needed because they were the key to solving a few basic problems of practical importance. The Soviets were attempting to forecast ship icing and also to provide their ships with efficient techniques for reducing the ice growth rate or preventing the ships from icing entirely. Since these two principal objectives of the Soviet research program were given by Borisenkov and Panov (1972) and mentioned again by Panov (1976), we can attempt to judge for what purposes the Soviets were using the data on the physical properties. First, a knowledge of the density of the accretion is necessary to calculate the ice loads due to icing, and the resulting ship stability. Second, the density of the accretion appears to be very important in the modelling of the growth of ice. Borisenkov and Panov (1972) pointed out that the Soviets had focussed on the forecasting of ship icing by the use of numerical physical models of the growth of ice. We rather suspect that the collection of the field data on these parameters was well correlated with the development of the related ship icing models (e.g., Borisenkov, 1969; Kachurin et al., 1974; Panov, 1976).

Third, the most challenging objective of the Soviet research program on ship icing was probably the development of efficient techniques for the de-icing of ships. The Soviets studied several techniques for reducing the icing rate and for removal of ice from the ship (Panov, 1976; Aksyutin, 1979). The Soviets had access to the foreign literature on the subject, as one can conclude from the extensive reviews given in Aksyutin (1979) and Panov (1976). Among all the techniques for the de-icing of ships, research on cryophobic materials appears to have been of greatest interest to the Soviets and was the best funded.

Special attention was therefore paid to the measurement of the adhesive strength of the accretion on various construction materials, and to the development of new materials with minimal adhesive strength for ice.

8.1. Soviet Data on the Density of Ice Accretion

The density of the accretion formed on a ship due to the freezing of spray has been measured on several Soviet ships. Probably the most detailed data were collected on the MFV "Academic Ber" (Japan Sea), the RV "Polyarnik" (Barents Sea), and on the MFT "8432" (probably in the Bering Sea) (Kuznietsov et al., 1969; Panov, 1976).

The density of the accretion varies from 0.71 to 0.96 g cm^{-3} (710 to 960 kg m^{-3}) (Panov, 1976). There is no relationship between the density of the newly-formed accretion and the location on the ship (Kuznietsov et al., 1969). This latter finding is in agreement with the results of Japanese studies (Tabata et al., 1963).

The Soviets used the field data on the accretion density to calculate ice loads due to icing and ship stability. In order to avoid

possible underestimation of the calculated ice loads on ships, Panov (1976) recommends that one should use a value of 940 kg m^{-3} for the density of the accretion. This postulated value of the accretion density is larger than the most commonly used value of 900 kg m^{-3} (e.g., Drevitch, 1975).

Very few data are available on the porosity of the accretion (the Soviets define the porosity of the accretion to be the fraction of the volume of the accretion without ice crystals). Panov (1976) quotes the data of Savyel'ev (1971a, 1971b) that refer to sea ice and also to ice accretions. Savyel'ev states that the porosity of the accretion varies from 0 to 50%. This means that up to 50% of the volume of the accretion consists of salt brine and air. Since the paper by Savyel'ev (1971b) is not available to us, we cannot give any other information on the porosity of the accretion, nor any details about the weather conditions which were associated with the growth of the accretions, or the techniques used for its measurement.

8.2. The Data on the Adhesive Strength of the Accretion

In order to measure the adhesive strength of the accretion on various surfaces, two adhesiometers were designed by Dr. Panyushkin from AANII (Panyushkin and Petrov, 1975; Panyushkin and Rozenberg, 1972) and produced in Leningrad. Several series of tests were conducted both at sea and in a land-based laboratory (AANII).

The field experiment was carried out on the MFV "Professor Somov" in the Barents Sea in the winters of 1968/69 and 1969/70 (Panyushkin and Rozenberg, 1972). The ship was carefully prepared for the installation of several mats of surface area on the ship ~0.5-1.0 m^2.

The mats were installed on the ship using special wooden and metallic frames. The following locations were chosen: (1) the ship bulwarks, (2) the front face of the ship superstructure, (3) above the fishing net winch near the ship superstructure, (4) on the gunwale and foredeck. By these means the Soviets were able to install the mats in both horizontal and vertical orientations (Fig. 8.1). The mats were covered with several different materials, many of which were developed and produced by the Soviet chemical industry, specifically for the USSR Ministry of Fisheries research program. Besides the field surveys on the MFV "Professor Somov" the Soviets conducted (Panov et al., 1975a) some additional surveys in the Japan Sea in February 1973 (most likely on the MFV "Narva"), and in October 1972, on one of their small fishing mother-ships (probably also in the Japan Sea). Similar tests were conducted on fishing vessels in the Baltic Sea (probably the MFV "Piarnu") in the winters of 1968/69 and 1969/70 (Panyushkin et al., 1972a).

There are several difficulties in the determination of the types and parameters of the surface materials, because they are coded by the Soviets using different symbols (e.g., "G", "V", or "FG"), but no details about their chemical structure are given. Ice growth was most significantly slowed down by applying the surface material of type "G" (Table 8.1). In fact, at the beginning of the icing event, this protective material resulted in temporary cessation of the ice growth (for the first 1.5 hours). The surface material of type "V" appears to be much less effective and its action was noticed only during the first hour of the icing event. Further, the ice was growing with an intensity almost the same as for the steel plate (2) coated with a regular marine

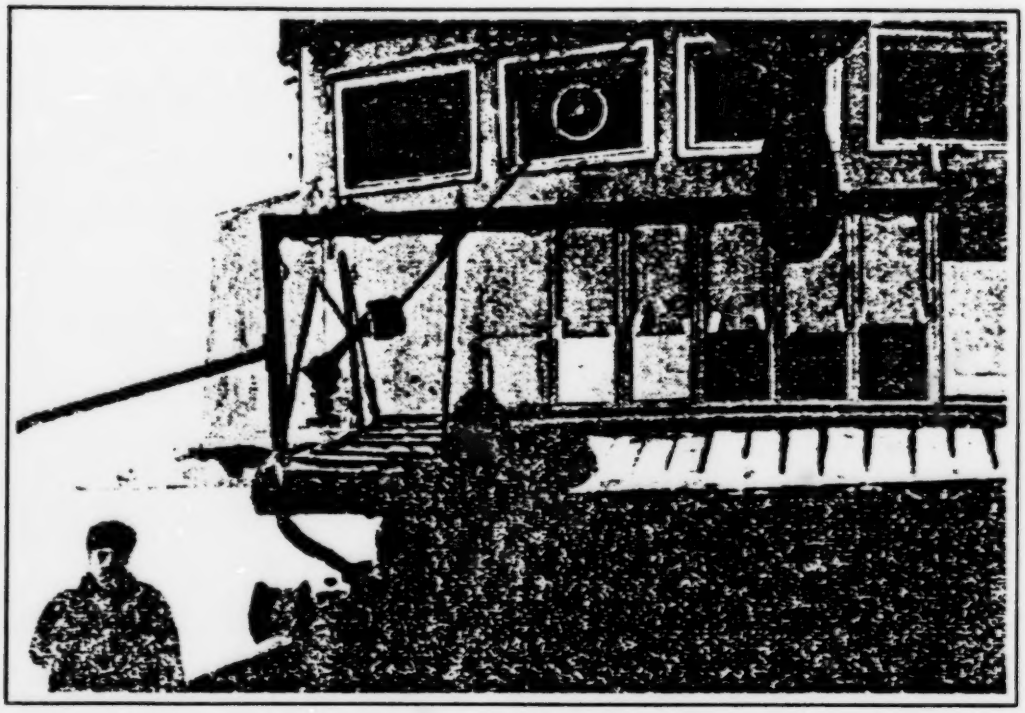


Fig. 8.1. The installation of mats covered with cryophobic coatings on an MFV (winter of 1968/69) (Panyushkin and Rozenberg, 1972).

Table 8.1. The results of observations of the surface materials during an icing event caused by freezing of collision-generated spray (winter 1968/69) (Panyushkin et al., 1972a).

Date	Icing Severity	Temperature (°C)		Wind speed $m\ s^{-1}$	Coating			
		air	sea surface		type "G"	type "FG"	type "V"	marine oil paint
Jan 29/69	light icing	0 to -2	1.5	14-15	frost	frost	frost	durable ice cover
Feb 8/69	moder-ate icing	-4 to -5	1.0-1.4	10-13	clean	slush	slush	thick ice layer

oil paint. The icing rate was the highest for plain wood, but for all other materials, excluding wood coated with material of type "G", the icing rates were also relatively high.

The results of the observations carried out when the ship was exposed to collision-generated spray have proven that the surface material of type "G" effectively prevents the growth of ice on protected ship components. Thus, a material of type "G" appears to be very promising. The Soviets had already tested this material in the winter of 1968/69 and had found it very effective (Panyushkin et al., 1972). They give only a very general remark regarding this material - "kremnioorganeopoksidnoye pokrytie tipa G". This may be translated as "silicon/epoxide organic resin" or a "silicon/epoxide polymer" of type "G". But there are no detailed specifications given.

During the experiments it was found that the surface materials covering the mats sometimes dramatically slowed the growth of ice, even though icing on other unprotected ship surfaces was progressing rapidly. The tests on the ships were conducted by observing the growth of ice on several mats during 'normal' splashing of the ship by collision-generated spray (Table 8.1), and during artificial spraying with sea water (Table 8.2). The tests were conducted for horizontally and vertically oriented mats covered with various surface materials (Table 8.3). The coating material of "G" type was found to be more effective than the other materials for both horizontally and vertically oriented test sections.

The "G" type silicone/epoxy coating was effective for both horizontally and vertically oriented mats. The smaller ice growth

Table 8.2. Icing rate on mats covered with different surface materials and sprayed with seawater by the crew (Panyushkin et al., 1972a).

Structural material	Surface material	Thickness (mm) of the accretion at various times					
		0.5 h	1.0 h	1.5 h	2.0 h	2.5 h	3.0 h
Duraluminum	marine oil paint	4	10	14	20	27	32
Steel (1)	marine oil paint	2	8	10	18	30	34
Steel (2)	marine oil paint	-	3	5	15	22	27
Duraluminum	"V" type	-	1	3	12	20	27
Wood	"G" type	-	-	-	3	6	6
Wood	marine oil paint	5	10	20	32	37	42

Table 8.3. Icing rate on various surfaces during 'natural' icing tests on an MFV on January 29, 1970 (Panyushkin et al. (1972a)). The air temperature was -0.2 to -2.8°C, the sea surface temperature +0.6 to 0.7°C, the wind speed 11 to 14 m s^{-1}.

Time from beginning of icing event (min)	Ice thickness (mm)									
	Type "G"		Polymer (unknown details)		Marine oil paint		Marine oil paint coated with polymer of unknown parameters		Marine oil paint coated with silicone resin	
	H	V	H	V	H	V	H	V	H	V
25	-	-	-	-	7.2	5	2	0.5	3	-
57	6	2	5	-	17	11	8.3	5.7	7.1	4.9
85	8.5	6.7	7	4	23.2	18	10	7.1	12.4	6.8
12.5	12	9.6	11	5	33.4	28	14	11.3	15.3	8.2

H horizontally oriented mat. V vertically oriented mat.

rate for the vertically-oriented surfaces seems to be caused by enhanced run-down of water impinging onto these coatings. The polymer and silicone coatings on a base of marine oil paint also appear to work effectively, especially for vertically-oriented surfaces. 'Regular' marine oil paint alone was found to enhance the ice growth unless its surface was coated with a polymer or silicone layer.

The adhesive strength of the accretion to the tested coatings measured on 19 January 1970 at an air temperature of -8.2°C and a sea surface temperature of 2.3°C is given in Table 8.4.

Table 8.4. Adhesive strength of ice (Panyushkin et al., 1972).

Type of coating	Adhesive strength (kg cm^{-2})
"G"	0.1
"Polymer" (no other details)	0.1
Marine oil paint	4.67
Marine oil paint coated with a polymer (no details available)	0.84
Marine oil paint coated with silicone resins	0.98

One can easily note that the coatings with a low adhesive strength for ice are also characterized by low icing rates (Table 8.4). The adhesive strength of the accretion to the 'regular' marine oil paint and to the silicone/epoxy coating of "G" type were measured at various air temperatures (Table 8.5). Basically, the adhesive strength increases as the temperature drops.

Table 8.5. The effect of air temperature and sea surface temperature on the adhesive strength of ice accretion to marine oil paint and the "G" type coating (Panyushkin et al., 1972a).

Coating	Temperature (°C)		Adhesive strength ($kg\ cm^{-2}$)
	water	air	
Marine oil paint	2.3	-8.2	4.67
	-1.8	-12.8	8.40
	-1.2	-15.0	9.70
Type "G"	2.3	-8.2	0.1
	-1.8	-12.8	0.27
	-1.2	-15.0	0.29

9. CONCLUSIONS

Our extensive search for field data on icing-related parameters collected by the Soviets led us to conclude that the Soviet research on ship icing has been very well developed. The search in question has proven that from 1967 to 1972, a vast ship icing data collecting program has been carried out on hundreds of Soviet ships. This program was launched following several ship losses that struck the Soviet fishing fleet in the 50s and 60s.

Data on icing-related parameters were collected using ship icing reports that were distributed on all Soviet ships scheduled for winter operation. In addition, several Soviet fishing vessels were recalled from service, equipped with specially designed measuring devices, and then sent to sea with scientists on board. To the best of our knowledge, the Soviet program in question was the largest ever launched.

Icing of ships is caused mainly by collision-generated spray. Dangerous icing has exclusively been caused by this spray on Soviet ships. The Soviet findings are well correlated with the data of Tabata et al. (1963) and Mertins (1968).

Western readers are provided with much new information about research on Soviet ship icing in this report, even though some of it (mostly on ship icing modelling and forecasting) has already been translated into English by the U.S. Army Cold Regions Research Engineering Laboratory. Perhaps the most valuable new data are that on splashing a ship with collision-generated spray, ice growth rates, and ice loads.

In most Soviet publications, explicit information is rarely given. As a result of cross-referencing, the duration, dates, areas,

and objectives and the names of ships participating in the Soviet field expeditions have been reconstructed (Table 2.1).

Our main effort was to introduce to Western readers the contents of the Soviet interdisciplinary program on ship icing and to produce a new independent data set on icing rates on ships.

Our compilation of ship icing rates measured on Soviet ships consists of 115 cases for which ship name, sea, date, magnitudes of the air-sea and ship motion parameters responsible for the growth of ice, and the icing rate have been carefully extracted from all available literature, often by means of cross referencing. It should be emphasized here, that we do not have access to the raw Soviet data, nor to their ship icing reports. The only source of our data compilation is the Soviet published papers on ship icing. Consequently, we cannot give here a complete assessment of the quality of the data compiled. The air-sea and ship motion parameters responsible for the growth of ice on a ship have been measured by the Soviets along with the overall icing rate (in tonnes per hour) on the entire vessel. The icing rate estimates were based on the measurements of the incremental ice thicknesses over the vessel and a single measurement of accretion density. This technique shows a significant advantage over visually estimating ice thickness (see Tabata et al., 1963; Stallabrass, 1980; Pease and Comiskey, 1986). Also, the air-sea and ship motion parameters were measured by the Soviet scientists rather than by untrained crew, as was the case for the North Atlantic and Alaskan data sets. We hope that our weather and ocean data sets are free of errors. However, because our compilation is only as good as the data available, we have

discovered some significant discrepancies between the icing rates quoted by two different authors for the same ship and the icing event! An example is the case of the RV "Piarnu," sailing in February 1969 in the Baltic Sea. For other suspect data, compiled in Table 6.1, we gave some comments regarding the quality of the data.

Since the presented icing rates have been collected on the Soviet ships, and it is known that icing rates are ship specific, there is still a need for generating a reliable data set for icing-related parameters on Canadian ships. Only by using the data collected on Canadian ships will one be able to calibrate a ship icing model for Canadian vessels.

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Table 6.1. A summary of documented cases of icing of Soviet ships extracted from miscellaneous Soviet reports.

Case No.	Date	Ship position	Ship	Ship type	Ship length (m)	Ship Motion Parameters: Speed ($m\ s^{-1}$)	Ship Motion Parameters: Course (deg)	Ship Motion Parameters: Heading (deg)	Wind: Direction (deg)	Wind: Speed[1] ($m\ s^{-1}$)	Air pressure (kPa)	Air temperature (°C)	Precipitation	Sea State	Wave height (m)	Sea surface temperature (°C)	Frequency of spraying (min^{-1})	Duration of icing event (h)	Local icing rate: Value ($cm\ h^{-1}$)	Local icing rate: Location[2]	Overall icing rate on entire ship[3] (tonnes/h)	Reference
1	17 Feb 1969	Barents Sea	"Zielenga"	S	~30	2.1	315	180	315	14	-	-17.0	-	-	-	+1.0	-	1	-	-	7.0	Gurvitch (1972)
2	25 Feb 1969	Barents Sea	RS "5276"	S	~30	3.1	200	155	225	16	-	-5.0	-	-	-	±0.0	-	4	-	-	8.5	Gurvitch (1972)
3	31 Mar 1972	Bering Sea (59-01N; 178-58W)	"Pogranitchnik Zmeyev"	MFT	~54	-	-	170	090	14-20	1018	-9.2	Snow	-	2.0	+0.3	5	11	-	-	5.5	Buyanov et al. (1975)
4	Jan 1969	Barents Sea	SRT "4457"	MFV	~35	0.5-1.0	-	-	315	18	-	-8.0	-	-	-	+2.0	-	30	-	-	8.2	Gurvitch (1972)
5	Dec 1967	Barents Sea	SRT "4424"	MFV	~35	4.1	-	-	090	6.5	-	-3.0	-	-	-	+3.0[3]	-	48	-	-	0.1	Gurvitch (1972)
6	7-9 Feb 1968	Barents Sea	SRT "187"	MFV	~35	0.5-1.5	000	140	040	17	-	-18.0	-	-	-	+2.0	-	48	-	-	0.3	Gurvitch (1972)
7	29 Jan 1969	Barents Sea	"Professor Somov"	MFV	39.2	2.6	360	50	230	14	-	-8.0	-	-	-	+1.0	-	8.5	-	-	1.7	Gurvitch (1972)
8	1 Feb 1969	Barents Sea	"Prof. Somov"	MFV	39.2	2.6	170	10	000	9-12	-	-10.0	-	-	-	+1.2	-	4	-	-	1.7	Gurvitch (1972)
9	1-2 Feb 1969	Barents Sea	"Prof. Somov"	MFV	39.2	2.6	260	120	200	11.6	-	-10.0	-	-	-	+1.0	-	2	-	-	6.2	Gurvitch (1972)
10	6 Feb 1969	Barents Sea	"Prof. Somov"	MFV	39.2	2.1	210	150	180	12.2	-	-11.2	-	-	-	+1.6	-	8	-	-	2.1	Gurvitch (1972)
11	6 Feb 1969	Barents Sea	"Prof. Somov"	MFV	39.2	2.1	210	150	180	16-19	-	-11.0	-	-	-	+0.8	-	2	-	-	6.1	Gurvitch (1972)
12	10-11 Feb 1969	Barents Sea	"Prof. Somov"	MFV	39.2	1.5	230	110	140	13-16	-	-9.0	-	-	-	+2.4	-	4	-	-	4.5	Gurvitch (1972)
13	12 Feb 1969	Barents Sea	"Prof. Somov"	MFV	39.2	2.1	250	120	190	6	-	-13.8	-	-	-	+0.8	-	4	-	-	2.8	Gurvitch (1972)
14	31 Oct 1968	Sea of Okhotsk	47 ships	MFV	~35	-	-	180	000	11-17	-	-7.5	-	-	-	0.0-1.0	-	-	0.8-1.1	deck, gunwale	-	Buyanov (1971a)
15	25 Oct 1968	Sea of Okhotsk	RS "Aktash"	S	~30	-	-	~180	315	6-10	-	-4.0	-	3	-	+1.0	2-3	2-3	0.1-0.2	bow, bulwarks	-	Buyanov (1971a)
16	30-31 Oct 1968	Sea of Okhotsk	11 ships	S	~35	1.5-2.0	000	180	000	11-17	-	-5.0	-	-	-	+1.0	-	-	0.3-0.4	unknown	-	Buyanov (1971a)
17	1 Nov 1968	Sea of Okhotsk	11 ships	S	~30	-	-	180	000	11-17	-	-6.0	-	-	-	+1.0	-	-	0.5-0.7	unknown	-	Buyanov (1971a)
18	1 Nov 1968	Sea of Okhotsk	RS "Volgograd"	S	~30	-	-	180	000	11-17	-	-7.0	-	-	-	+1.0	-	-	0.7	unknown	-	Buyanov (1971a)
19	1 Nov 1968	Sea of Okhotsk	RS "Volgograd"	S	~30	-	-	180	000	11-17	-	-7.0	-	-	-	0.0	-	-	0.9	unknown	-	Buyanov (1971a)
20	1 Nov 1968	Sea of Okhotsk	RS "Volgograd"	S	~30	-	-	180	000	11-17	-	-9.0	-	-	-	0.0	-	-	1.1	unknown	-	Buyanov (1971a)
21	28 Feb 1969	Barents Sea	RV "Iceberg"	MFV	39.2	3.6	280	140	240	17	-	-4.2	-	-	-	-0.2	-	13	-	-	0.75	Gurvitch (1972)
22	1 Apr 1968	Barents Sea	RV "Polyarnik"	MFV	38.5	2.6	360	80	260	14	-	-10.0	-	-	-	1.8	-	20	-	-	0.4	Gurvitch (1972)
23	21 Apr 1968	Barents Sea	RV "Polyarnik"	MFV	38.5	2.1	360	150	330	12-17	-	-4.0	-	-	-	-1.0	-	12	-	-	0.3	Gurvitch (1972)
24	25 Apr 1968	Barents Sea	RV "Polyarnik"	MFV	38.5	2.1	360	150	330	7-15	-	-12.0	-	-	-	-1.8	-	3.5	-	-	2.8	Gurvitch (1972)
25	5 Mar 1968	Barents Sea	"Aland"	MFT	54.0	4.6	360	130	50	17.4	-	-10.8	-	-	-	-1.6	-	1	-	-	7.3	Gurvitch (1972)
26	5 Mar 1968	Barents Sea	"Aland"	MFT	54.0	4.6	100	130	50	13.2	-	-12.2	-	-	-	-1.6	-	1	-	-	5.0	Gurvitch (1972)
27	14 Mar 1968	Barents Sea	"Smelyi"	FMS	-	1.5	-	-	270	18.0	-	-7.1	-	-	-	-1.5	-	27	-	-	0.5	Gurvitch (1972)
28	30 Jan 1968	Barents Sea	"Smelyi"	FMS	-	5.6	-	-	190	11	-	-3.1	-	-	-	+5.0	-	9	-	-	2.3	Gurvitch (1972)
29	16-18 Feb 1968	Barents Sea	"Smelyi"	FMS	-	2.6	290	60	170	12	-	-6.1	-	-	-	-1.4	-	60	-	-	3.4	Gurvitch (1972)
30	8 Mar 1968	Barents Sea	"Smelyi"	FMS	-	2.6	-	-	100	10	-	-3.0	-	-	-	-1.3	-	3	-	-	4.6	Gurvitch (1972)
31	7 Jan 1969	Baltic Sea	"Zaporozhets"	ST	<30	3.6	200	115	135	14	-	-11.0	-	-	-	+2.0	-	9.5	-	-	0.66	Gurvitch (1972)
32	5 Jan 1969	Baltic Sea	MRT - 186	ST	<30	-	010	72	118	11	-	-11.0	-	-	-	+3.0	-	10	-	-	0.28	Gurvitch (1972)
33	19 Jan 1969	Baltic Sea	"Shushtche"	ST	<30	4.8	080	125	135	20	-	-3.0	-	-	-	0.0-1.0	-	3.5	-	-	3.90[4]	Gurvitch (1972)
34	13 Feb 1969	Baltic Sea	RR - 1285	UF	-	2.1	090	135	45	14	-	-7.0	-	-	-	+5.0	-	16	-	-	0.62	Gurvitch (1972)
35	5 Jan 1969	Baltic Sea	RR - 1287	UF	-	3.1	136	159	157	15	-	-17.0	-	-	-	+3.0	-	9	-	-	0.78	Gurvitch (1972)
36	-	Sea of Okhotsk 120 mi from Kamchatka	"Tulona"	C	110	-	315	180	315	32	-	-8.0	-	-	-	+1.0	-	7	2.0-7.0	over the ship		Buyanov (1968)
37	-	5-7 mi from Kamchatka Coast	5 ships	MFV	~39	0-0.5	315	180	315	32	-	-20.0	-	-	-	+1.0	-	14	3.0,3.5	rigging, upper deck		Buyanov (1968)
38	4 Jan 1968	Baltic Sea	"Eskimo"	MFV	~39	-	000	135	315	20	-	-6.0	-	-	-	-	-	6	-	-	1.5	Gurvitch (1972)
39	16 Feb 1969	Baltic Sea	SRT - 4540	MFV	~39	2.1-3.1	072	175	67½	13	-	-10.0	-	-	-	+5.0	-	20	-	-	0.15	Gurvitch (1972)
40	11 Feb 1969	Baltic Sea	SRT - 4450	MFV	~39	1.5	130	170	120	17.6	-	-6.0	-	-	-	-	-	5	-	-	1.0	Gurvitch (1972)
41	15 Feb 1969	Baltic Sea	SRT - 4444	MFV	~39	4.1	072	153	45	4.2**	-	-10.0	-	-	-	0.0	-	16	-	-	0.37	Gurvitch (1972)
42	13 Feb 1969	Baltic Sea	SRT - 4300	MFV	~39	4.1	095	130	45	5.0	-	-10.0	-	-	-	-0.5	-	23	-	-	0.52	Gurvitch (1972)
43	6 Jan 1969	Baltic Sea	SRT - 4241	MFV	~39	4.6	072	102	150	7.0	-	-4.-	-	-	-	-1.5	-	4	-	-	1.0	Gurvitch (1972)
44	9 Feb 1969	Baltic Sea	SRT - 4426	MFV	~39	4.6	075	53	202	12	-	-9.0	-	-	-	+1.9	-	5	-	-	0.54	Gurvitch (1972)
45	9 Feb 1969	Baltic Sea	SRT - 4438	MFV	~39	3.3	073	73	180	5	-	-3.0	-	-	-	+2.0	-	3	-	-	0.67	Gurvitch (1972)
46	8 Feb 1969	Baltic Sea	SRT - 4571	MFV	~39	4.1	072	82	170	25*	-	-9.0	-	-	-	+1.0	-	1	-	-	5.5	Gurvitch (1972)
47	20-23 Feb 1969	Baltic Sea	SRT - 4585	MFV	~39	4.1	090	135	135	11	-	-6.0	-	-	-	+2.0	-	58	-	-	0.1	Gurvitch (1972)
48	14-15 Feb 1969	Baltic Sea	"Stephan Andryeev"	MFV	~39	4.4	083	97	000	14	-	-4.0	-	-	-	+0.7	-	9	-	-	1.0	Gurvitch (1972)
49	20 Jan 1969	Baltic Sea	SRT - 4316	MFV	~39	-	090	135	135	14	-	-5.0	-	-	-	-	-	15	-	-	0.7	Gurvitch (1972)
50	10 Feb 1969	Baltic Sea	SRT - 4325	MFV	~39	3.8	089	157	112	8.5	-	-8.0	-	-	-	-	-	6	-	-	1.8	Gurvitch (1972)
51	27 Dec 1961	Baltic Sea	"Aksai"	MFV	~39	-	315	180	315	17	-	-6.0	-	-	-	-	-	3	-	-	4.2	Gurvitch (1972)
52	1 Feb 1967	Unknown	Buksir "P"	TB	28.9	-	-	180	-	14-20	-	-15.0	-	-	-	-	-	-	2.0	-	-	Aksyutin (1979)
53	5 Oct 1956	Laptlev Sea	Unknown	RV	-	-	-	180	-	≥28.5	-	-7+-8	-	6-7	-	0.0	-	-	30-50	main deck	-	Kovrova et al. (1969)
54	20-21 Feb 1966	Bering Sea 3 miles off Utashud Is.	Trawler "j"	T	34.9	0-0.5	-	180	-	40	-	-20.0	-	-	-	-1.0	-	-	60-90	front face of ship superstructure	-	Aksyutin (1979)
55	8 Feb 1969	Baltic Sea	"Piarnu"	MFV	39.15	0.5	180	160	160	15.2	-	-4.2	-	-	-	-0.2	-	0.5	-	-	12.0[7]	Gurvitch (1972)
56	8 Feb 1969	Baltic Sea	"Piarnu"	MFV	39.15	2.6	200	140	160	14.8	-	-4.5	-	-	-	-0.3	-	0.5	-	-	6.0[7]	Gurvitch (1972)
57	8 Feb 1969	Baltic Sea	"Piarnu"	MFV	39.15	1.8	160	80	60	12.4	-	-5.6	-	-	-	+0.5	-	0.5	-	-	6.0[7]	Gurvitch (1972)
58	8 Feb 1969	Baltic Sea	"Piarnu"	MFV	39.15	2.3	090	105	15	14.0	-	-4.6	-	-	-	-0.1	-	0.5	-	-	12.0[7]	Gurvitch (1972)
59	9 Feb 1969	Baltic Sea	"Piarnu"	MFV	39.15	2.6	095	115	30	13.8	-	-6.6	-	-	-	-0.4	-	0.5	-	-	44.0[7]	Gurvitch (1972)
60	10 Feb 1969	Baltic Sea	"Piarnu"	MFV	39.15	4.6	095	115	30	13.8	-	-5.7	-	-	-	-0.4	-	0.5	-	-	28.0[7]	Gurvitch (1972)
61	19 Feb 1969	Baltic Sea	"Piarnu"	MFV	39.15	1.5	150	169	139	8.6	-	-6.9	-	-	-	-1.3	-	0.5	-	-	14.0[7]	Gurvitch (1972)
62	31 Dec 1961-1 Jan 1962	Bering Sea 68 mi W of St. Paul Is.	Trawler "K"	MFV	34.2	-	045	180	45	8-14	-	-12+-17	-	5	-	0.0	-	-	-	-	1.4-1.7	Aksyutin (1979)
63	9 Mar 1960	Baltic Sea	"Orion"	MFV	~35	-	088	178	90	14	-	-2.0	-	-	-	+2.6	-	5	-	-	5.0	Gurvitch (1972)
64	30 Jan-1 Feb 1967	Skagerrak	"Merkurii"	MFT	~54	6.0	090	18	90	17	-	-8.0	-	-	-	-	-	39	-	-	1.64	Gurvitch (1972)
65	4-5 Feb 1968	Bering Sea	"Kedrovyi"	MFV	~39	0.5-1.0	000	147	33	15-17	-	-7+-12	-	-	-	+1.0	-	6.5	-	-	5.9	Gurvitch (1972)
66	21 Feb 1968	Bering Sea	"Konus"	MRT	43-51[5]	3.6	060	75	315	7-8	-	-8.0	-	-	-	-	-	17	-	-	0.9	Gurvitch (1972)
67	8 Feb 1968	Bering Sea	"Konus"	MRT	43-51[5]	3.1	030	150	000	7-8	-	-12.0	-	-	-	-	-	8	-	-	3.0	Gurvitch (1972)
68	1 Mar 1968	Bering Sea	"Konus"	MRT	43-51[5]	2.8	020	160	000	7-8	-	-6.0	-	-	-	-	-	10	-	-	2.2	Gurvitch (1972)
69	4 Feb 1968	Bering Sea	"Konus"	MRT	43-51[5]	3.1	020	160	000	7-8	-	-10.0	-	-	-	-	-	12	-	-	0.5	Gurvitch (1972)
																-2.0		12			2.5	Gurvitch (1972)

49	20 Jan 1969	Baltic Sea	SRT - 4316	MFV	-39	-	090	135	135	14	-	-5.0	-	-	-	-	-	15	-	-	0.7	
50	10 Feb 1969	Baltic Sea	SRT - 4325	MFV	-39	3.8	089	157	112	8.5	-	-8.0	-	-	-	-	-	6	-	-	1.8	Gurvitch (1972)
51	27 Dec 1961	Baltic Sea	"Aksai"	MFV	-39	-	315	180	315	17	-	-6.0	-	-	-	-	-	3	-	-	4.2	Gurvitch (1972)
52	1 Feb 1967	Unknown	Buksir "P"	TB	28.9	-	-	180	-	14-20	-	-15.0	-	-	-	-	-	-	2.0	-	-	Aksyutin (1979)
53	5 Oct 1956	Laptlev Sea	Unknown	RV	-	-	-	180	-	≥28.5	-	-7÷-8	-	6-7	-	0.0	-	-	30-50	main deck	-	Kovrova et al. (1969)
54	20-21 Feb 1966	Bering Sea 3 miles off Utashud Is.	Trawler "I"	T	34.9	0-0.5	-	180	-	40	-	-20.0	-	-	-	-1.0	-	-	60-90	front face of ship superstructure	-	Aksyutin (1979)
55	8 Feb 1969	Baltic Sea	"Piarnu"	MFV	39.15	0.5	180	160	160	15.2	-	-4.2	-	-	-	-0.2	-	0.5	-	-	12.0[7]	Gurvitch (1972)
56	8 Feb 1969	Baltic Sea	"Piarnu"	MFV	39.15	2.6	200	140	160	14.8	-	-4.5	-	-	-	-0.3	-	0.5	-	-	6.0[7]	Gurvitch (1972)
57	8 Feb 1969	Baltic Sea	"Piarnu"	MFV	39.15	1.8	160	80	60	12.4	-	-5.6	-	-	-	+0.5	-	0.5	-	-	6.0[7]	Gurvitch (1972)
58	8 Feb 1969	Baltic Sea	"Piarnu"	MFV	39.15	2.3	090	105	15	14.0	-	-4.6	-	-	-	-0.1	-	0.5	-	-	12.0[7]	Gurvitch (1972)
59	9 Feb 1969	Baltic Sea	"Piarnu"	MFV	39.15	2.6	095	115	30	13.8	-	-6.6	-	-	-	-0.4	-	0.5	-	-	44.0[7]	Gurvitch (1972)
60	10 Feb 1969	Baltic Sea	"Piarnu"	MFV	39.15	4.6	09[illegible]	115	30	13.8	-	-5.7	-	-	-	-0.4	-	0.5	-	-	28.0[7]	Gurvitch (1972)
61	19 Feb 1969	Baltic Sea	"Piarnu"	MFV	39.15	1.5	150	169	139	8.6	-	-6.9	-	-	-	-1.3	-	0.5	-	-	14.0[7]	Gurvitch (1972)
62	31 Dec 1961-1 Jan 1962	Bering Sea 68 mi W of St. Paul Is.	Trawler "K"	MFV	34.2	-	045	180	45	8-14	-	-12÷-17	-	5	-	0.0	-	-	-	-	1.4-1.7	Aksyutin (1979)
63	9 Mar 1960	Baltic Sea	"Orion"	MFV	-35	-	088	178	90	14	-	-2.0	-	-	-	+2.6	-	5	-	-	5.0	Gurvitch (1972)
64	30 Jan-1 Feb 1967	Skagerrak	"Merkurij"	MFT	-54	6.0	090	18	90	17	-	-8.0	-	-	-	-	-	39	-	-	1.64	Gurvitch (1972)
65	4-5 Feb 1968	Bering Sea	"Kedrovyi"	MFV	-39	0.5-1.0	080	147	33	15-17	-	-7÷-12	-	-	-	+1.0	-	6.5	-	-	5.9	Gurvitch (1972)
66	21 Feb 1968	Bering Sea	"Konus"	MRT	43-51[4]	3.6	060	75	315	7-8	-	-8.0	-	-	-	-	-	17	-	-	0.9	Gurvitch (1972)
67	8 Feb 1968	Bering Sea	"Konus"	MRT	43-51[4]	3.1	030	150	000	7-8	-	-12.0	-	-	-	-	-	8	-	-	3.0	Gurvitch (1972)
68	1 Mar 1968	Bering Sea	"Konus"	MRT	43-51[4]	2.8	020	160	000	7-8	-	-6.0	-	-	-	-	-	10	-	-	2.2	Gurvitch (1972)
69	4 Feb 1968	Bering Sea	"Konus"	MRT	43-51[4]	3.1	020	160	000	7-8	-	-10.0	-	-	-	-	-	12	-	-	0.5	Gurvitch (1972)
70	Dec 1963	Bering Sea	"Sevastopol"	MRT	43-51[4]	5.1	045	180	45	10	-	-22.0	-	-	-	-2.0	-	12	-	-	2.5	Gurvitch (1972)
71	1 Feb 1969	Bering Sea	SRMT - 8482	MFT	-54	4.7	030	50	160	19	-	-10.0	-	-	-	-0.6	-	6	-	-	2.7	Gurvitch (1972)
72	3 Feb 1969	Bering Sea	SRMT - 8482	MFT	-54	4.6	071	153	44	15	-	-13.8	-	-	-	-0.1	-	4	-	-	2.6	Gurvitch (1972)
73	6 Feb 1969	Bering Sea	SRMT - 8482	MFT	-54	4.6	270	60	150	23	-	-14.1	-	-	-	+0.7	-	6	-	-	8.6	Gurvitch (1972)
74	5 Feb 1969	Bering Sea	SRMT - 8439	MFT	-54	-	-	-	360	11.4	-	-8.0	-	-	-	+1.1	-	12	-	-	1.7	Gurvitch (1972)
75	4 Feb 1969	Bering Sea	SRMT - 8439	MFT	-54	-	-	-	360	10.3	-	-8.0	-	-	-	+1.1	-	12	-	-	5.3	Gurvitch (1972)
76	23 Dec 1967	Bering Sea	"Dekabrist"	FMS	-	-	-	180	-	0.0	-	-7.0	-	-	-	-2.0	-	24	-	-	1.6	Gurvitch (1972)
77	22 Dec 1967	Bering Sea	"Dekabrist"	FMS	-	-	-	180	270	3.0	-	-6.0	-	-	-	-2.0	-	12	-	-	4.2	Gurvitch (1972)
78	19 Jan 1965	Bering Sea	"Ataman"	MFV	-35	-	-	180	-	25-30	-	-12.0	-	-	-	-1.0	-	-	-	-	15-20	Tsoy (1968), Aksyutin (1979)
79	19 Feb 1965	Bering Sea 100 mi from St. Mateo Is. & 60 mi fr. St. Paul Is.	"Boksitogorsk"	MFT	34.8	0.5-1.0	0.0	-	90	25-30	-	-22.0	Snow[4]	-	6-7	-1.0	-	-	-	-	10-15[5]	Tsoy (1968), Aksyutin (1979)
80	15-16 Nov 1966	Sea of Okhotsk RS-812	"Onlega"	S	-30	3.8	220	85	315	9-10	-	-10.0	-	-	-	+2.0	-	12	-	-	0.75	Gurvitch (1972)
81	5 Jan 1968	Sea of Okhotsk	"Vitiaz'"	MFV	-39	-	-	180	320	25-29	-	-3.0	-	-	-	+1.0	-	28	-	-	0.90	Gurvitch (1972)
82	4 Jan 1968	Sea of Okhotsk	"Vitiaz'"	MFV	-39	-	-	-	90	19-21	-	-2.0	-	-	-	+1.0	-	12	-	-	0.75	Gurvitch (1972)
83	7 Jan 1968	Sea of Okhotsk	"Dekabrist"	FMS	-	-	-	180	315	14	-	-9.0	-	-	-	-2.0	-	12	-	-	4.25	Gurvitch (1972)
84	6 Jan 1968	Sea of Okhotsk	"Dekabrist"	FMS	-	-	-	180	270	24	-	-12.0	-	-	-	-2.0	-	12	-	-	5.4	Gurvitch (1972)
85	5 Jan 1968	Sea of Okhotsk	"Dekabrist"	FMS	-	-	-	180	270	11	-	-9.0	-	-	-	-2.0	-	24	-	-	3.13	Gurvitch (1972)
86	4 Jan 1968	Sea of Okhotsk	"Dekabrist"	FMS	-	-	-	180	45	11	-	-6.0	-	-	-	-2.0	-	24	-	-	2.1	Gurvitch (1972)
87	12 Jan 1969	Japan Sea	"Academic Ber"	MFV	39.5	4.6	-291	140	330	10-15	1025	-10.8	-	-	-	0.5-0.8	-	6	0.2-1.3 0.6-1.3 0.8-1.3	deck superstructure mast	2.3	Panov (1971a), Gurvitch (1972)
88	7 Feb 1972	Bering Sea	"Pogranitch-nik Zmyeev"	MFT	-54	-1.6-2.6	180	30	30	18	-992	-5.4	-	-	5.0	+2.5	3-4	2	-	-	1.7	Buyanov et al. (1975)
89	7 Feb 1972	Bering Sea	"Pog. n. Zmy."	MFT	-54	1.6	015	165	30	18	-992	-5.3	-	-	5.0	+2.5	3-4	2	-	-	0.3	Buyanov et al. (1975)
90	7 Feb 1972	Bering Sea	"Pog. n. Zmy."	MFT	-54	1.6	030	180-170	30	18	-992	-5.6	-	-	5.0	+2.4	3-4	2	-	-	0.5	Buyanov et al. (1975)
91	7 Feb 1972	Bering Sea	"Pog. n. Zmy."	MFT	-54	1.6	020	180-170	30	18	-992	-6.6	-	-	5.5	+2.2	3-4	2	-	-	0.7	Buyanov et al. (1975)
92	7 Feb 1972	Bering Sea	"Pog. n. Zmy."	MFT	-54	0.5	020	180-170	30	17	-992	-8.6	-	-	5.0	+1.4	3-4	2	-	-	0.8	Buyanov et al. (1975)
93	7 Feb 1972	Bering Sea	"Pog. n. Zmy."	MFT	-54	0.5	020	170-160	30	14	-992	-10.1	-	-	5.5	+1.2	3-4	2	-	-	2.9	Buyanov et al. (1975)
94	8 Feb 1972	Bering Sea	"Pog. n. Zmy."	MFT	-54	1.0	015	175	10	13	-992	-11.1	-	-	5.0	+1.1	2-3	3	-	-	1.6	Buyanov et al. (1975)
95	8 Feb 1972	Bering Sea	"Pog. n. Zmy."	MFT	-54	2.1	015	175	10	13	-992	-11.6	-	-	4.0	+1.0	2-3	2	-	-	1.2	Buyanov et al. (1975)
96	8 Feb 1972	Bering Sea	"Pog. n. Zmy."	MFT	-54	2.1	015	155	10	13	-992	-11.7	-	-	4.0	+0.6	2-3	2	-	-	1.2	Buyanov et al. (1975)
97	8 Feb 1972	Bering Sea	"Pog. n. Zmy."	MFT	-54	3.1	340	150	10	13	-992	-10.3	-	-	3.5	+0.6	1-2	2	-	-	1.2	Buyanov et al. (1975)
98	8 Feb 1972	Bering Sea	"Pog. n. Zmy."	MFT	-54	4.1	360	160	20	16	-992	-15.0	-	-	3.5	-1.6	0-1	12	-	-	6.6	Buyanov et al. (1975)
99	19 Jan 1969	Japan Sea	"Academic Ber"	MFV	39.5	4.6	300	120	360	13-14	-	-5.4	-	-	-	+0.6	-	3	-	-	1.0	Gurvitch (1972)
100	23-24 Jan 1969	Japan Sea	"Academic Ber"	MFV	39.5	4.6	285	115	350	14-15	-	-14.9	-	-	-	-1.1	-	8	-	-	2.7	Gurvitch (1972)
101	27 Jan 1969	Japan Sea	"Academic Ber"	MFV	39.5	4.6	180	10-20	10-20	6-7		-7.0	-	-	-	+1.0	-	1	-	-	1.2	Gurvitch (1972)
102	1-2 Feb 1969	Japan Sea	"Academic Ber"	MFV	39.5	4.1-4.6	288	138	330	15-17	-	-11.8	-	-	-	+0.3	-	7	-	-	3.0	Gurvitch (1972)
103	3 Feb 1969	Japan Sea	"Academic Ber"	MFV	39.5	4.6	350	170	340	13-15	-	-9.5	-	-	-	0.0	-	3	-	-	3.37	Gurvitch (1972)
104	5 Feb 1969	Japan Sea	"Academic Ber"	MFV	39.5	3.6-4.6	340	160	320	18-21	-	-13.2	-	-	-	+0.9	-	3	-	-	2.1	Gurvitch (1972)
105	6 Feb 1969	Japan Sea	"Academic Ber"	MFV	39.5	4.1	340	170	330	17	-	-14.1	-	-	-	+0.9	-	3	-	-	3.3	Gurvitch (1972)
106	13 Feb 1969	Japan Sea	"Academic Ber"	MFV	39.5	4.6	310	170	300	14-18	-	-10.2	-	-	-	+0.5	-	5	-	-	1.6	Gurvitch (1972)
107	28 Dec 1967	Japan Sea	"Roslavl'"	FMS	-	-	-	-	337½	8-9	-	-20.8	-	-	-	-	-	12	-	-	2.5	Gurvitch (1972)
108	27 Dec 1967	Japan Sea	"Roslavl'"	FMS	-	6.2	042	115	337	6-7	-	-15.0	-	-	-	-	-	18	-	-	2.0	Gurvitch (1972)
109	27 Dec 1967	Japan Sea	"Atlasov"	FMS	-	5.1	325	165	340	13-16	-	-15÷-17	-	-	-	0.0	-	4	-	-	7.0	Gurvitch (1972)
110	7 Feb 1969	Baltic Sea	"Piarnu"	MFV	39.15	variable	-	-	-	12.7	-	0÷-1	-	-	-	-0.0	-	12	-	-	0.25	Rybnikov (1975)
111	8 Feb 1969	Baltic Sea	"Piarnu"	MFV	39.15	variable	-	-	-	-	-	<0	-	-	-	-0.0	-	9	-	-	0.33	Rybnikov (1975)
112	8 Feb 1969	Baltic Sea	"Piarnu"	MFV	39.15	2.6	-200	-115	-135	11-17	-	-5.0	-	-	-	-0.2	-	6	-	-	1.0	Rybnikov (1975)
113	8 Feb 1969	Baltic Sea	"Piarnu"	MFV	39.15	2.3[8]	090	135	135	11-17	-	-5.0	-	-	-	-0.1[8]	-	3	-	-	2.0	Rybnikov (1975)
114	8 Feb 1969	Baltic Sea	"Piarnu"	MFV	39.15	2.3[8]	090	135	135	14-21	-	-5.0	-	-	-	-0.1÷-0.4[8]	-	3	-	-	2.7	Rybnikov (1975)
115	8-9 Feb 1969	Baltic Sea	"Piarnu"	MFV	39.15	4.6	095	140	135	14-21	-	-5.7[8]			-	-0.4[8]	-	6	-	-	4.7	Rybnikov (1975)

[1] If the report gives only the wind force in Beaufort, a wind speed is given here in m s^{-1} according to the Beaufort scale.
[2] If the object was specified.
[3] Mean for the entire icing event.
[4] The length for MRTS of "Okean" and "Bologoye" type is given.
[5] Information from vessels which survived the icing storm (the "Boksitogorsk" sank).
[6] As given in the reference, but doubtful because of relatively warm air.
[7] We doubt whether the quoted icing rate is correct. Please see cases nos. 112-115 reconstructed using the report of Rybnikov (1975).
[8] Parameters extracted from Gurvitch (1972) because Rybnikov (1975) did not list them.

* most likely in sheltered waters
** conditions of swell occurred

Ship types: C - cargo; FMS - fishing mother ship; MFV - medium-sized fishing vessel; MFT - medium-sized freezing trawler; MRT - medium-sized refrigerating trawler; RV - research vessel; S - seiner; ST - small trawler; T - trawler; TB - tug boat; UF - fishing vessel of unknown type.